

Correlation in price changes and volatility between non-deliverable forward and spot markets

An analysis of daily data from China

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Abstract

This thesis seeks to explore the dynamics between China's onshore spot foreign exchange market and the offshore RMB non-deliverable forward (NDF) market before and after the reforms in exchange rate regime and foreign exchange market structures around July 21, 2005. Developments in the two markets are reviewed and daily closing rates of both markets are examined. The Johansen co-integration test finds a strong co-integrating relationship between the onshore spot rate and the NDF rate and a two-way Granger causality is detected. An augmented GARCH formulation is employed to model the inter-market mean and volatility spillover effects. Evidence of strong mean spillover effects in both directions is observed but no significant volatility spillover is identified.

Preface

A teacher affects eternity: he can never tell where his influence stops.

~ Henry Adams

This thesis can never be finished without the supervision of Dr. Roger Hammersland, a great supervisor and friend. I'd like to express my utmost gratitude to him for his patient guidance, earnest help and constant encouragement, for inspiring my interest in econometric works and for believing in me, to all of which I'll always be indebted.

Professor Zhang Jikang at Fudan University in China led me into the research field in China's foreign exchange market. I can never measure the influence he has on me for being what he is, and neither can I measure the pain that the loss of him has caused. May he rest in peace!

I'd also like to thank my fiancé for taking good care of me and offering endless support when I was busy working on this thesis.

Finally, to my parents who teach me about dignity, courage and hope, who always stand up for me during times of difficulties and whom I can always turn to for advice and selfless love, this thesis is for you!

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1. Introduction

On July 21, 2005, China's central bank announced a reform of RMB exchange rate regime featuring a 2% appreciation of RMB against US dollar and a basket peg¹. In spite of its limited success in achieving enough flexibility in the exchange rate regime and in fending off speculations on the further appreciation of the Chinese currency, this reform has indeed in many ways changed market behavior. Shortly before and after that reform, a series of reform measures was carried out in the onshore foreign exchange market broadening market access, diversifying trading products and transforming trading mechanisms. These measures have been able to lessen the degree of exchange rate rigidity, improve the market structure, restore the previously distorted supply and demand mechanism, render the "market" a more important role in exchange rate determination and not least, subject the formerly insulated domestic foreign exchange market to influences from other markets. Among them, the RMB non-deliverable forward (NDF) market² is an obvious candidate.

Speculative interests in the appreciation of RMB has injected huge liquidity into the RMB NDF market and boosted turnover from an average daily level of around \$ 50 million to about \$ 200 million in early 2003 (Ma et al., 2004). Even though the offshore NDF market and onshore spot market have been divided by strict capital control measures and have seen many differences in their operations (see relevant discussion in chapter 2), the similarity of the underlying asset that they trade, the increasing participation in the NDF market by domestic institutions and certain degree of inter-market capital as well as information flows made possible by the reforms has made the topic of exploring market dynamics between the two markets extremely interesting and feasible.

Transmission of price and volatility among financial markets is not an unfamiliar topic in the literature, probably inspired by the contagion across different markets during the Asian financial crisis and the apparent increasing integration of international financial markets. A substantive body of literature has studied the price and volatility spillover effects between

¹ A more precise expression should be: determine the exchange rate level "with reference to" a basket of currencies so that the central bank can still have some discretion with respect to the determination of exchange rate.

² A formal definition of the NDF market will be given in chapter 2.

different market locations and research has mainly focused on three types of financial markets: the equity market, money market and foreign exchange market.

Many studies find an interdependence of price changes and volatility across international stock markets (Eun and Shim, 1989; King and Wadhwani, 1990; Hamao et al., 1990; Lin et al., 1994) and some have focused on volatility and price change spillover effects across developed markets and emerging markets (Hu et al., 1997; Liu and Pan, 1997; Wei et al., 1995; Park and Fatemi, 1993). Hamao et al. (1990) modeled the transmission mechanisms of the conditional first and second moments in common stock prices across Tokyo, London and New York stock markets, utilizing the Autoregressive Conditional Heteroscedastic (ARCH) approach and observed price volatility spillovers from the New York to Tokyo, London to Tokyo, and New York to London market.

In research concerning the money market, a lot of efforts have been dedicated to exploring the transmission between interest rate series in domestic markets and offshore markets and structural changes in the direction of causality have been observed by many. For the US dollar markets, innovations in domestic interest rates are found to lead offshore Eurodollar markets in the earlier periods (Kaen and Hachey, 1983; Hartman, 1984; Swanson, 1988) but reversed causality has been strengthened over the years (Fung and Isberg, 1992). Lo, Fung and Morse (1995), studying interest rate transmission between the Euroyen market and the Japanese domestic CD market, has found a co-integration relationship between the two interest rate series and strong feedback effects in both directions in more recent years.

The foreign exchange market has also received considerable attention in this direction. In their seminal work, Engle, Ito and Lin (1990), using meteorological analogies, tested the hypotheses of “heat wave” or existence of only country-specific autocorrelation in volatility and that of “meteor shower” which supports interregional volatility spillovers. Applying a GARCH model to intra-daily yen/dollar exchange rate in the New York market and Tokyo market, they soundly rejected the “heat wave” hypothesis and reported evidence in favor of a spillover effect in volatility between different market locations. Baillie and Bollerslev (1990) based their study on hourly data of four major exchange rates across different world markets. They confirmed the meteor shower hypothesis and identified the presence of a seasonal ARCH term which suggested some heat wave characteristics. Melvin and Peiers (2003) has also found a co-existence of statistically significant “heat-wave” (own-region) effects and

“meteor shower” (inter-regional spillovers) effects but has argued that “heat-waves” are more significant economically (larger in magnitude) than “meteor showers” and thus more important. Park (2001) turned to the Korean markets for potential price changes and volatility spillover effects between the domestic Won-Dollar market and the NDF market utilizing daily closing rates. He divided the sample data into the two subsets of the pre-reform period and post-reform period according to Korea’s foreign exchange rate system in December 1997³. He too adopted the GARCH formulation and found a unidirectional mean spillover effect from the spot to the NDF market in the pre-reform period but a reversed relationship after the reform. With respect to volatility spillovers, both directions existed in the pre-reform period but in the post-reform period, only the volatility of the NDF market seemed to influence the spot market and not vice versa.

As can be seen in the discussion above, the application of the ARCH/GARCH family of statistical models to describe foreign exchange rate data is pervasive in the literature (See also Domowitz and Hakkio, 1985; Engle and Bollerslev, 1986; Diebold and Nerlove, 1989; Hodrick, 1989). Information clustering in the arrival process of news or market participants’ lagged response may well explain this ARCH behavior of exchange rates. Traders in the market usually have heterogeneous prior expectations and private information⁴, so after a shock or incoming of new information, they still have to take some hours of trading to resolve this prior expectational difference, causing a continuation of volatility.

Inspired by previous literature on inter-market transmission of price changes and volatility as well as recent reforms in China’s foreign exchange market, this thesis will study the dynamics between China’s onshore spot market and the RMB NDF market. Chapter 2 will review the developments in the two markets and chapter 3 will constitute the empirical study of market inter-relations. Following the line of Park (2001), daily closing rates in the two markets are used and divided into a pre-reform period (January 4, 1999-July 20, 2005) and a post-reform period (July 21, 2005-March 30, 2006) but only the post-reform period will be the focus of our research⁵. Preliminary statistics describing the dataset will be provided, followed by econometric tests for stationarity, co-integrated relationships and directions of causality. An AR (1)-GARCH (1, 1) model for the NDF rate change and an AR (1)-GARCH_t (1, 1) model

³ This reform installed a free-floating exchange rate regime and deregulated the foreign exchange market.

⁴ Existence of private information and heterogeneous beliefs constitutes an important part of market microstructure theory. See Sarno and Taylor (2001).

⁵ See later sections for an explanation.

for the spot rate change will be employed to test for potential across market mean and volatility spillover effects. Mean spillovers from the spot to the NDF market and from the NDF to the spot market are strongly significant but no obvious volatility spillover in either direction emerges in the post-reform period. Chapter 4 gives the summary and concludes. The findings of this thesis can not only provide further evidence of the price and volatility transmission mechanism across financial markets, especially for the onshore and offshore market, but also have important policy implications for the policy-making practice in China's foreign exchange market.

For market participants, increasing interests of domestic institutions to participate in the NDF market for risk-hedging (since they're exposed to greater exchange rate risks after the regime change) or speculation has necessitated the knowledge of cross-market relations to better manage their portfolios and control risk exposures. For the central bank, after the new reforms, the domestic foreign exchange market is no longer insulated from influences from the offshore market or overseas market and the central bank no longer has the kind of absolute control as under the old fixed exchange rate regime, so a thorough understanding of inter-market relations will be crucial to avoid potential contagion of violent rate movements from the highly speculative offshore market to the domestic spot market. In addition, the inter-market relations will be even strengthened when the capital control measures phase out and cross-border capital flows become more frequent, thus the underlying risk to financial stability can not be overlooked. The central bank should ponder on the sequence of financial deregulations to minimize the risk brought by inter-market spillover effects. As will be shown in chapter 2, an onshore forward market has just been established. How to deal with the co-existence of these two forward markets and let the onshore market lead instead of being dominated by the NDF market is also an issue on the authorities' agenda.

The empirical work in this thesis has been performed using GiveWin 2.02/PcGive.

2. Foreign exchange market organizations in China

Explanations of the empirical results about mean and volatility spillovers between the onshore spot and offshore forward market as well as important policy implications can't be achieved without a sound knowledge of the foreign exchange rate regime and foreign exchange market organizations in China. In chapter 2, we will begin with a review of the historical development of China's foreign exchange market and go on to examine the institutional framework governing the market as well as the market structures. A discussion of the development and characteristics of the RMB NDF market follows and at the end of the chapter, differences and connections between the two markets will be explored.

2.1 Historical development of China's foreign exchange market⁶

2.1.1 *Pre-1979: Strict Central Control*

Before 1979, China had a highly centralized regime governing the supply, demand and allocation of foreign exchange. All foreign exchange earnings (mainly export proceeds) had to be surrendered to the state-owned banks and the central bank, i.e. the People's Bank of China (PBOC). All foreign exchange expenditures (i.e., for imports or non-trade purposes) had to be approved under the confines of the national foreign exchange plan which leaned toward the state sector.⁷ There was no market element in the formation of the exchange rate which was fixed to the British pound from 1952, then to a basket of international currencies from 1973.

2.1.2 *1979-1993: foreign exchange Retention and Swap*

Liberalization of foreign exchange use began in 1979 with an earnings retention scheme designed to encourage exports. Under this scheme, exporters were entitled to retain a share of their foreign exchange earnings, initially with respect to exports above some quota but from 1998 according to the full measure of exports. From 1981 to 1984, exchange rates were set differentially for trade and non-trade activities⁸.

⁶ China's foreign exchange market is herein referred to as the onshore foreign exchange market.

⁷ The foreign exchange plan was formulated by the State Planning Commission in consultation with the Ministries of Trade and Finance and the PBOC. (See Zhang, Z.C., 2003)

⁸ The exchange rate for trade activities was set at 2.8 RMB/USD while the official rate still stood at 1.5 RMB/USD. This practice was abolished since January 1, 1985.

The first sign of an actual foreign exchange market in China appeared in October 1980 when retained foreign exchange claims became transferable, first through the swap service launched by the PBOC, then in provincial swap centers, and finally in an integrated nationwide swap market.⁹ The late 1980s saw the expansion of foreign exchange swap activity with the number of market participants increasing and swap exchange rates becoming more flexible. By the end of 1993, there were 108 local swap centers and 18 markets joined to the nationwide system. A mechanism for forming a market exchange rate had thereby been established in coexistence with an official pegged rate.

The development of the swap market with its diversity of swap rates had its own problems, including discrimination, rent-seeking and unauthorized actions. Nevertheless, it acted as a transitional device to lay a foundation for the emergence of a true foreign exchange market in China. The 1979-1994 period also saw frequent adjustments of the official exchange rate¹⁰ with a trend devaluation of RMB against US dollar. After the gradual devaluations of the official rate, the central bank was well prepared to unify the exchange rates and reform the exchange rate regime.

2.1.3 1994 and Post-1994: Compulsory Settlement on a Centralised Platform

The year 1994 was a turning point in China's foreign exchange reform. In that year, the system of foreign exchange retention and submission that had existed for 15 years was replaced with a compulsory settlement system under which foreign exchange earners were obligated to sell their foreign exchange to state banks while foreign exchange users could buy it subject to conditions. The "single managed floating exchange rate regime based on market supply and demand" was adopted. On 4 April 1994, the China Foreign Exchange Trading System (CFETS) began operation, signifying the launch of a unified national inter-bank foreign exchange market. The government's foreign exchange management method was also adjusted to rely more on systematic economic and legal measures in contrast with the former command approach. New rules governing the purchase of foreign exchange by individuals for overseas visits, study or other personal needs took effect on 1 April. These rules have been relaxed gradually over time with the upper limit on individual purchases raised to \$8000¹¹

⁹ Despite the name, the swap market provided spot transactions only.

¹⁰ These adjustments were frequent, small and slow with mixed appreciation and depreciations but on the whole, RMB had been devalued against US dollar from the early 1979 level of 1.50 RMB/USD to 5.72 RMB/USD at the end of 1993. Six large official devaluations took place in 1981, 1984, 1985, 1986, 1989 and 1990.

¹¹ As of August, 2005. The limit has been revised to \$ 20,000 per person/per year, coming into effect on May 1,

from an initial \$600 per person/visit. The success of the 1994 reform enabled conditional convertibility of the RMB for current account related transactions and brought a real foreign exchange market into existence.

Reform continued under the basic framework of the foreign exchange purchase and sale system after 1994. In 1995, China ended the circulation of foreign exchange certificates¹². In July 1996, the foreign exchange transactions of Foreign Invested Enterprises (FIEs) were integrated into the foreign exchange purchase and sale system, allowing FIEs to buy foreign currency freely on the inter-bank market. On 27 November 1996, China formally notified the International Monetary Fund of the RMB's convertibility under the current account. Qualified Chinese companies were allowed to open foreign exchange settlement accounts to retain a proportion of foreign exchange earnings from current account transactions in 1997. Bank of China was authorized to launch the forward foreign exchange purchase and sale business with its customers in 1997.

The Asian financial crisis interrupted China's aggressive reform timetable. A series of regulations were enacted and clarified by the PBOC to strengthen the responsibilities of the State Administration of Foreign Exchange (SAFE) with respect to falsely obtaining foreign exchange, failing to surrender foreign exchange, illegal arbitrage and so on. The swap centers were closed on December 1, 1998, with all foreign exchange transactions thereafter integrated into the foreign exchange purchase and sale system.

In 2001, trading in dollar-denominated B shares on China's stock market was opened to Chinese nationals (having formerly been limited to foreign passport holders) with necessary currency exchange supported by CFETS. Trading in euros was introduced in April 2002. Then in October 2002, all enterprises that qualified for conducting international business or had regular foreign exchange incomes from current account transactions, were allowed to open foreign currency accounts for holding up to 20 percent of their previous year's foreign exchange income. Two-way trading was permitted from October 2003 with trading hours extended from half to full day. 2005 is another landmark in the development of China's foreign exchange market abundant with policy initiatives. Eight foreign currency pairs started

2006.

¹² Foreign exchange certificates (FEC) are notes equivalent in value to the RMB Yuan. Foreigners can exchange foreign currency into FECs and use them to make payments during their stay in China (They can not directly exchange foreign currency into RMB).

trading in the inter-bank market in May 2005. The RMB was revalued with a 2% appreciation against US dollar and the peg to the single US dollar was replaced with a reference to a basket of currencies in July 2005. The July 21 reform was followed by successive reform measures in August¹³ to enlarge the scope of forward transactions and swaps in the retail market, to invite non-financial enterprises and non-bank financial institutions to participate in the inter-bank market, to add a quote-driven dealer market trading mechanism into the current auction market and to introduce inter-bank foreign exchange forward and swap trading. In addition, a long expected market maker system for USD/RMB trade was finally announced in November 2005 based on the CFETS platform¹⁴.

2.2 Trading mechanism and market activity: 1994-2004

2.2.1 Market composition

China's foreign exchange market is composed of two parts: the inter-bank or wholesale market and the retail market (see Figure A.1.1 in Appendix 1). Major parties involved in the foreign exchange market are: 1. CFETS which functions as the trading platform for the inter-bank market and is responsible for clearing the market and for providing the supervisory authorities with market information. 2. PBOC and SAFE as regulatory authorities: the PBOC authorized SAFE to regulate the inter-bank spot and forward markets and the retail market. 3. Designated foreign exchange banks and other non-bank financial institutions¹⁵ authorized by SAFE to engage in foreign exchange business. 4. Enterprises that earn and spend foreign exchange. 5. Individuals who have foreign exchange trading needs. The nature of the inter-bank foreign exchange market is for designated foreign exchange banks to square their foreign exchange positions derived from retail foreign exchange business after maintaining an allowable foreign exchange working position¹⁶. Before the August 2005 reform, the inter-bank market has been a centralized order-driven auction market making use of organized exchange trading and an electronic broking system while retail transactions have been carried out in an over-the-counter (OTC) market.

CFETS: The Trading Platform

¹³ Details of these policies can be seen in the "Notice of the People's Bank of China on Accelerating the Development of the Foreign Exchange Market" which came out on August 8, 2005 on the central bank's website: www.pbc.gov.cn

¹⁴ Details can be found on the State Administration of Foreign Exchange's website: www.safe.gov.cn, November 27, 2005

¹⁵ Non-financial enterprises weren't allowed access until the August 2005 reform.

¹⁶ This allowable foreign exchange working position has to be verified and approved by SAFE.

CFETS is a membership-based foreign exchange trading platform with a nationwide real-time electronic trading system. With an “auction market” trading mechanism similar to an electronic broker, members make back-to-back (anonymous) quotes on the trading platform through either on-site or distant trading terminals. The electronic trading platform automatically enables real-time matching of orders. The clearing function is integrated into the CFETS platform, providing members with centralized, two-way, netting/clearing of RMB and foreign currencies.

This market infrastructure was originally put in place to serve the needs of the compulsory foreign exchange settlement system and to facilitate the PBOC’s absolute control of the market. But now it seems inevitable that a voluntary foreign exchange settlement system will be adopted, and the necessity for the CFETS to clear excess supply or demand will no longer exist. Thus the question is whether or not this inefficient non-market-oriented trading platform should be retained once there is no longer a need for centralized and compulsory settlement of foreign exchange.

The pros and cons must be considered in order to make the decision. A trading platform such as the CFETS had its justifications in connection with a developing and fragile financial system. Risk management and pricing is not well-developed in China. With a fragile banking industry and lack of bilateral credit lines, the exchange mode and automated trading system provided by the CFETS provides a centralized credit system to overcome the credit risk concerns.

In addition, advances in telecommunications and information technology have already led to a large share of trading being snapped up by electronic brokers such as Electronic Broking Services Ltd.(EBS) and Reuters offering lower transaction costs and tighter spreads through the use of STP (Straight-Through-Processing) and CLS (Continuous Linked Settlement) as well as greater transparency in pricing. The CFETS platform functions similarly to electronic brokers and may fit the future trend in global foreign exchange markets.

However as an administrative unit of the PBOC, the CFETS suffers from inefficiencies due to monopoly power and a non-market orientation. The CFETS is used by the central bank to control the market and is exposed to neither competition nor supervision by its members.

In summary, recent policy moves offer a clue that the central bank won't easily let go of the CFETS as the trading platform in the inter-bank foreign exchange market. The existence of such a platform will ensure that further reforms in the foreign exchange market are carried out under the central bank's scrutinization and enable the central bank to calculate order flow directly. In the meantime, the CFETS must undergo major transformations with respect to market-orientation, services offered, technology, efficiency, and risk management. The possible direction of reform will lean towards introducing new elements to the old platform so that China's inter-bank market will become indeed a mixed market with a centralized auction market and a parallel dealer market for certain transactions. There's a large chance that the CFETS will continue to function as a transaction and information market platform but it should become more independent of the central bank in the sense that it should spin off the current supervision responsibility administered by the central bank.

2.2.2 Market activity

Market Turnover: a shallow and narrow market

Average daily turnover in China's inter-bank foreign exchange market is very low compared to that on the world's major markets (see Table 2.1). But China's market is growing fast with daily turnover up by 177 per cent in 2004 relative to 2001.

The small scale of China's foreign exchange market is attributable in part to institutional factors. Restrictions on foreign exchange holdings of both commercial banks and the public significantly limit the development of the market. So too does concentration of foreign exchange trading among a few large banks that tend to balance trades internally, turning to the inter-bank market just once a day to re-establish their reserves at the allowable level. Indeed, until October 2003, buying and selling during the same trading session was prohibited. Market development is also inhibited by capital control measures and the limited scope of products and currencies.

Table 2.1: Foreign Exchange Market Daily Average Turnover in Selected Markets, 1995-2004

	(USD billion/day)			
	1995	1998	2001	2004
China	0.26	0.21	0.30	0.83
Hong Kong	90	79	67	102
Japan	161	136	147	199
Singapore	105	139	101	125
United Kingdom	464	637	504	753
United States	244	351	254	461

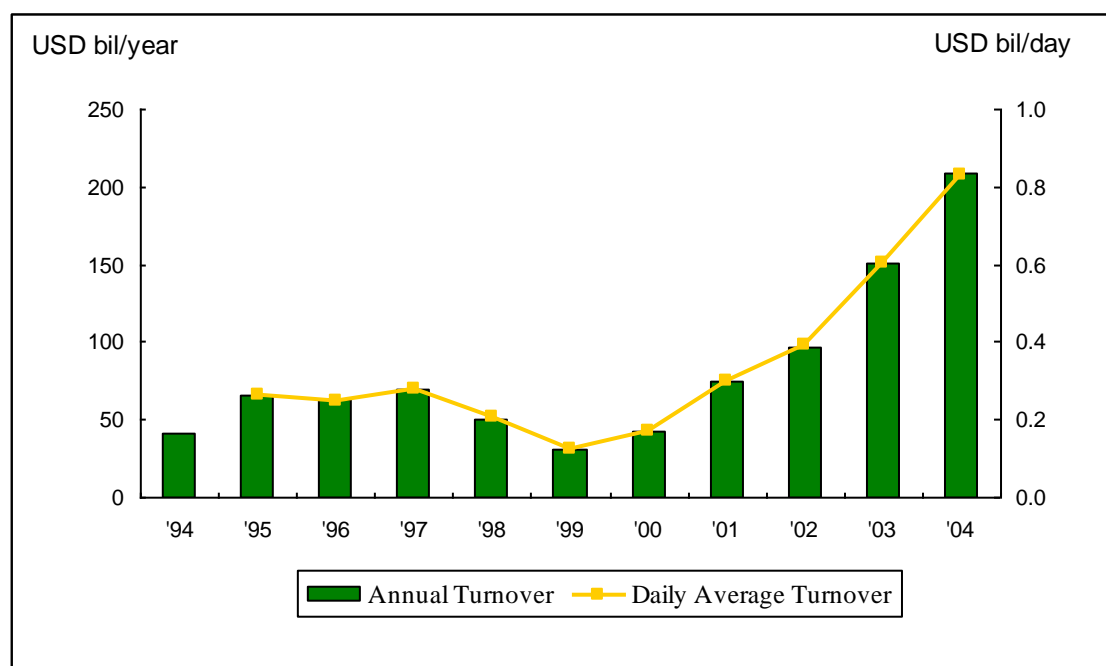
Source: CFETS, BIS Triennial Survey.

Note: For markets other than China's, daily averages are for the month of April and cover spot, forward and swap transactions. For China, volume is based on the entire year and pertains only to inter-bank spot transactions.

The recent dramatic growth in China's inter-bank market follows a sluggish start in the 1990s (see Figure 2.1). The years 1997 to 1999 actually showed a downturn from which the market did not re-emerge until 2001. With recovery of economic growth domestically, China's admission to WTO and improvement in the foreign trade and investment balance, the market picked up momentum entering a period of fast growth from 2001 to 2004 with an average growth rate of 50.32%. Market turnover reached a new height of USD209 billion in 2004 with a daily average of USD830 million.

The rising turnover on China's inter-bank market coincided with rapid growth in balance of payments flows. Under the compulsory foreign exchange purchase and sale system, the inter-bank market functions solely for banks to net out foreign exchange positions derived from retail trade. This retail trade is in turn driven by bank customer activity captured by the current and capital accounts transactions. In recent years, short-term capital inflows have played a major role in feeding the increase in supply of the RMB on the foreign exchange market, driven largely by expectations of an appreciation.

Figure 2.1: Annual and Daily Average Turnover in China's foreign exchange Market, 1994-2004



Source: *China Money*, different issues from 2001-2005

The July 2005 reform heralded reforms in the RMB exchange rate regime. With more flexibility in the exchange rate formation mechanism being introduced in the future, China will be expecting larger variations in its foreign exchange market. A small and shallow market is certainly no boon to smoothing exchange rate variations. This may add to authorities' concern to allow further flexibility in the exchange rate regime and cause delay in the reform timetable; on the other hand, without a more flexible rate, a truly deep market is hard to be achieved.

Market Segments: mainly a spot market dominated by RMB/USD trading

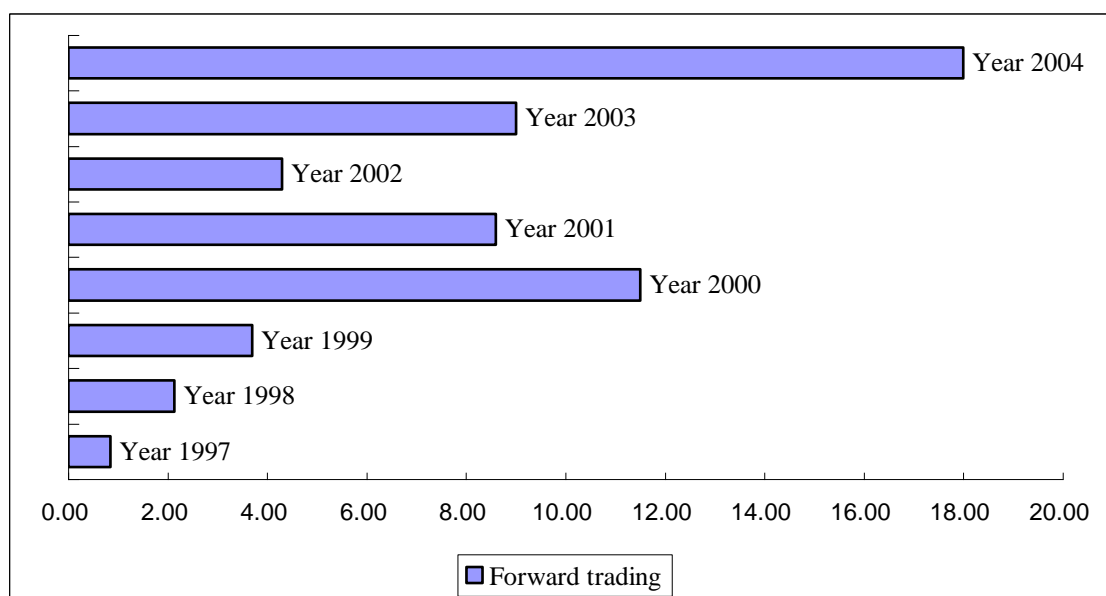
China's foreign exchange market is limited in product scope mainly to spot trading in US dollars. For a long time since its establishment, the inter-bank market offered only spot transactions. In August 2005, however inter-bank forward and swap transactions were introduced. In the retail market, the Bank of China (BOC) was allowed to offer forwards¹⁷

¹⁷ Presently, forwards exist in eight currencies (US dollar, Hong Kong dollar, euro, yen, pound, Swiss franc, Australian dollar and Canadian dollar) and 14 different terms from seven days to 12 months.

beginning in 1997, with the other banks following suit after 2002. Foreign exchange swaps in the retail market wasn't allowed until August 2005.

From the inception of forward transactions in 1997, the Bank of China's trading volume rose to a peak of USD11.5 billion in 2000 (see Figure 2.2). This growth reflected a need for businesses to hedge against currency risk during a period when the RMB was under pressure to depreciate in the wake of the Asian financial crisis. Rather than devalue though, the PBOC responded to the crisis by tightening the floating band. This led to a highly stable relationship between the RMB and the US dollar. Under such conditions, the need to hedge risk diminished and the forward market contracted. In 2002, the BOC's forward trading volume declined by about two-thirds from its peak. Since 2003, however, the market has rebounded driven by appreciation expectations and when more banks entered the business.

Figure 2.2: Retail Market Forward Foreign Exchange Trading
(USD billion)



Source: Data for year 1997-2002 are from *Bank of China Annual Reports* while data for year 2003-2004 are estimates made by ZHANG Guang Ping, chief financial engineering specialist from Shanghai Futures Exchange.

Compared with the global foreign exchange market, the lack of product range in the Chinese market restricts overall growth in market turnover and limits the functions of the market, especially the risk-hedging function.

China's foreign exchange market is limited, too, by its trading concentration in the US dollar. When the inter-bank market was established in 1994, only the US dollar and Hong Kong dollar were traded. The yen was added in 1995 and the euro in 2002. Eight foreign currency pairs started spot trading in May 2005. The US dollar, however, remains the overwhelmingly dominant currency, accounting for 97.78% of total turnover in 2004.

The high concentration in US dollar trading is not inconsistent with the important role the dollar plays in global trade and investment as a vehicle currency. Further, given the highly stable RMB/USD exchange rate, conducting their affairs in dollars allows those engaged in international business to minimize exchange risk. Having come to take stability of the exchange rate for granted, market participants do not net out their open positions immediately, but rather minimize transaction costs by netting out positions internally. Therefore, US dollar domination of the foreign exchange market is also a factor in the low level of overall market activity.

The US dollar domination in China's foreign exchange market reflects market participants' dependence on the central bank to clear the market under the rigid exchange rate regime. Lack of motivation to hedge two-way exchange risks also has prevented participants from building up professional skills in foreign exchange risk management and has retarded the development of foreign exchange derivatives, which may turn out to be one of the most important fragilities when exit from the current peg brings in more variations in the rates.

To sum up, China's inter-bank foreign exchange market is currently mainly a spot market. The forward and swap markets have just emerged with trivial volume so far. Even with the introduction of eight foreign currency pairs in 2005, the domination of RMB/USD trading is unlikely to be changed in the near future. The lack of diversity with respect to transaction types restrains market turnover and limits liquidity.

Market Participants and Concentration: restricted market entry and high concentration

Though membership in the CFETS reached 366 by June 2005, market activity remained highly concentrated among a small number of banks. This contrasts with the diverse body of market participants in the global foreign exchange market which includes dealers and non-financial entities as well as banks and non-bank financial institutions. The global foreign

exchange market has seen an increasing share of turnover being seized by trading between banks and other financial institutions which stood at 33% in 2004¹⁸.

Table 2.2: Market Concentration

Measure	Percentage
C1	50.57%
C2	64.70%
C3	71.71%
C4	76.14%
C5	79.86%

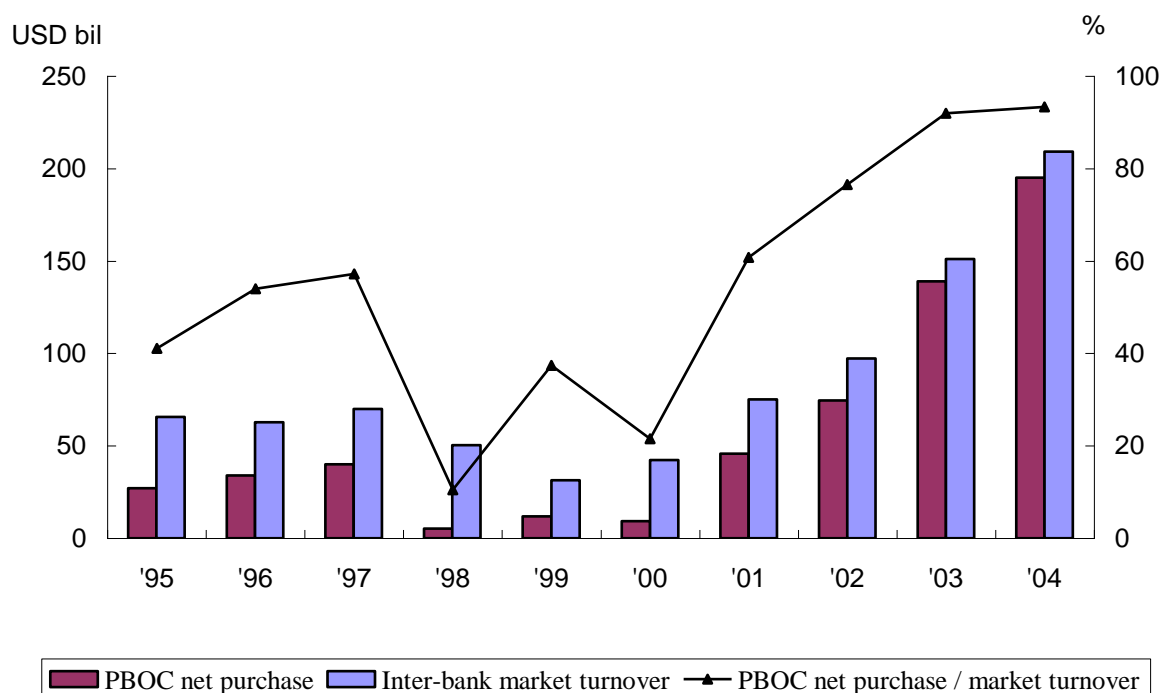
Note: C1 indicates the market share of the market participant with largest trading volume and C5 indicates the market share of the largest five participants. Calculation based on trading volume figures in *China Money*.

China's foreign exchange market is characterized by approaching monopoly especially on the buy side. Although nearly half of the CFETS's 366 members are foreign banks, their trading volume amounts to only a small portion of the total. In 2004, top 5 market participants¹⁹ covered nearly 80% of the total market trading (See table 2.2), all of them being domestic banks. These large banks are usually net sellers in the market with the rest of the participants being net buyers. The Bank of China itself is estimated to account for more than half of the net foreign exchange selling in 2002 (Wang, 2004). On the buy side, in the period from 1995 to 2004, PBOC's net purchase of foreign exchange accounted for 68 per cent of the total inter-bank market turnover (Calculated from figure 2.3).

¹⁸ See Bank for International Settlements (BIS), "Triennial Central Bank Survey of foreign exchange and Derivatives Market Activity in 2001", www.bis.org, July 15, 2004

¹⁹ They are Bank of China, Agriculture Bank of China, Industrial & Commercial Bank of China, China Construction Bank and China International Trust & Investment Corporation (CITIC).

Figure 2.3: PBOC Net Purchase of foreign exchange & Inter-Bank Market Turnover, 1995-2004



Source: Shu Youdong, "The Appreciation Pressure on RMB and the Releasing Measures", *China Money*, November 2001; Ernest H. Preeg, "Statement before the U.S.-China Economic and Security Review Commission", September 2003; "Central Bank Spends More Keeping Yuan Stable", www.chinaview.cn, March 2005.

In recent years, the PBOC has been obliged to undertake massive buying in the face of heavy supply pressure brought on by speculation of a RMB appreciation and a relatively high interest rate paid on RMB deposits. The result has been a rapid increase in official reserve assets to USD 875 billion at the end of March 2006.

2.3 New reform measures shortly before and after July 21, 2005

Shortly before²⁰ and after the July 21 reform, a series of new reforms were introduced to improve foreign exchange market structures and to loosen capital controls.

The reforms in the foreign exchange market mainly focused on three aspects: to broaden the market access, enrich market segments and to transform trading arrangements. Theoretically, these new reform measures can improve on the market structures in ways of increasing liquidity and enhancing market functions. Besides these foreign exchange market structural

²⁰ Referring to the launch of eight foreign currency pairs in May 2005.

changes, capital account liberalization were also pushed forward, partly to ease the appreciation pressure. These measures will leave domestic institutions as well as individuals with more freedom to acquire, transact and manage foreign currency and enlarge the scale of cross-border capital flows. With the new exchange rate regime and new parallel reforms in the foreign exchange market and capital account liberalization in place, the RMB exchange rate will be increasingly steered by market forces and the central bank and other market participants' role in the foreign exchange market will be transformed. As a result, the domestic foreign exchange market will receive more foreign influences, become less insulated from and more integrated to overseas foreign exchange markets, including the RMB offshore market.

2.3.1 Broaden Market Access

Non-financial enterprises and non-bank financial institutions were granted access to the domestic inter-bank foreign exchange market in August 2005. As of March 2006, there are 389 CFETS members, an increase of 23 compared with June 2005. Among the new participants, Sinochem Corporation became the first non-financial enterprise ever to enter the inter-bank market. Meanwhile, foreign banks continue to show a strong interest in China's foreign exchange market and have become the leading force in reforming China's foreign exchange market (see table 2.3).

Table 2.3: Number of institutions registered as participants in different market segments at the end of 2005

	Number of total participants	Number of foreign institutions
Inter-bank spot market (Members of CFETS)*	389	189
Inter-bank forward market	68	52
Foreign currency pairs trading	52	24
Forward purchase and sales (Retail Market)	46	30
Swap of RMB against foreign currencies	7	0
USD/RMB market makers in the quote-driven spot market	13	5

* Participant number is updated to March 2006 for the inter-bank spot market.

With their rich experience of foreign exchange trading, sophisticated foreign exchange risk management skills, deep understanding of the international foreign exchange market practice and sufficient and amicable relationship with the Chinese authority, foreign institutions will become the pillar in new products trading and the nascent market segments, many of them playing the role of market makers²¹. Active participation and a gesture of goodwill to help develop China's foreign exchange market can be seen as these foreign banks' preemptive strategic move to build a competitive edge in RMB trading and to seek new sources of profit growth with the realization of their full access into China's banking sector around the corner²². No matter what their motives are, foreign banks' presence in China's foreign

²¹ Market-making currently exists in the foreign currency pairs trading, inter-bank forward market and the quote-driven system of the inter-bank spot market.

²² As part of China's WTO commitment, the domestic banking sector will be fully opened to foreign banks by

exchange market means potential technology spillovers to their domestic counterparts and can help jump-start the new foreign exchange market. But they will also make the domestic foreign exchange market more susceptible to foreign influences and facilitate foreign capital flows in and out of the market.

With a combined export and import standing at USD1422.12 Billion in 2005²³, non-financial enterprises, especially companies in the foreign trade business have every reason to become big players in the foreign exchange market. However, the long-term super stable exchange rate has caused inertia among Chinese enterprises to hedge against foreign exchange risks. Lack of foreign exchange risk management awareness and skills as well as cost concerns²⁴ may prevent small enterprises from being deeply involved in the inter-bank market. As a result, those actively involved will be large enterprises, at least in the beginning. These large enterprises have had a history of participating in the overseas foreign exchange market and especially the RMB offshore market. Once granted access to the domestic foreign exchange markets, their potential arbitrage activities will bring further integration of the domestic market with the offshore market.

2.3.2 Enrich market segments

Measures to enrich foreign exchange market segments mainly include²⁵ adding 8 foreign currency pairs in the spot market and establishing an inter-bank forward market. This will enrich the original inter-bank market segment which only has spot transactions in four RMB related currency pairs, enhance the market functions and provide market participants with a new scope for investing their foreign exchange holdings as well as hedging against foreign exchange risks.

Inter-bank forward market

Establishing the inter-bank forward market is the key to making China's foreign exchange market a truly functional market which can satisfy market participants' risk hedging needs. Yet so far, the onshore forward market has not lived up to its expectations and has suffered from a low level of market activity (see table 2.4).

the end of 2006.

²³ Data from the Ministry of Commerce of the People's Republic of China website, 2006-04-09

²⁴ 54.7% of exports in 2005 are in the processing trade which tends to have a relatively low degree of risk exposure and small margins.

²⁵ Other measures such as expanding the retail market forward foreign exchange settlement business to all foreign exchange designated banks and introducing swap transactions will not be discussed in this thesis.

Table 2.4: Monthly number of transactions²⁶ in the inter-bank forward market

Month	Number of transactions
August 2005	8
September 2005	23
October 2005	38
November 2005	94
December 2005	114

Source: *China Money*, issue 7, 2005-issue 2, 2006

Among the 277 market transactions in 2005, 263 belong to RMB/USD forwards trading while 14 represent RMB/JPY trading. Term structures are quite diversified with 7 different terms for USD forwards and 4 for JPY forwards. The most liquid terms are 1 month and 12 month USD forwards.

Lack of liquidity and limited scale are common for a nascent market and the onshore market has to face the competition from the RMB NDF market (see below for a discussion of the NDF market), a market offering products of similar functions and with a longer history. As a result, since its establishment, quotes in the onshore forward market follow that in the RMB NDF market closely.

The underdeveloped money market in China may be the first to blame for the lack of independent pricing in the forward market. So far, China's money market remains an inefficient market rather than a market where highly liquid products with a whole spectrum of maturities are traded. The determination of interest rates is still regulated by the central bank. As a result, no representative market interest rate indices in different maturities are formed²⁷ and the onshore forward has thus no interest rate to base the interest rate parity on. Second, as mentioned above, the RMB NDF market has 10 more years of history and a higher liquidity than the onshore market, so the forward rate formed in the NDF market has naturally constituted a reference system for the rate movements in the onshore forward market. Considering the self-fulfilling quality of market liquidity, the onshore market is already lagging behind. The absence of an independent and more rational pricing in the onshore market means that its risk hedging functions will be limited and that it will be in a disadvantageous position in its competition with the NDF market.

²⁶ Unfortunately, the trading volume information isn't disclosed to the public and thus can't be obtained.

²⁷ The only "market" interest rate in China is the 7 day repo rate.

2.3.3 Transform trading arrangements

After the market making system and quote-driven dealer market system were introduced on January 4, 2006, China's foreign exchange market became a quasi-centralized hybrid market featuring coexistence of a quote-driven dealer market and an order-driven auction market utilizing a electronic broking system. These two transformations in trading arrangements represent milestones in China's foreign exchange market reform and will have far-reaching influences on the market structure, exchange rate formation mechanism as well as the central bank's monetary policy.

Diversified market liquidity provision mechanism

Providing liquidity is the primary role of a market maker. Market makers regularly quote both bid and ask prices and stand ready to buy and sell at the quoted prices. They can absorb excess market supply or demand by holding inventory and make a profit through bid/ask spreads. The role of market makers is thus crucial in achieving market clearing and providing liquidity. The market making system is especially important to nascent markets which often suffer from low liquidity or one-sided markets. With a mixed quote-driven dealer market and order-driven auction market structure, liquidity can be provided through multiple mechanisms and market participants are given more flexibility in choosing trading arrangements depending on the purposes of the transaction, the type of counterparty, the level of the transparency, the information they have and the size of the order (Harris, 2002). The biggest problem in China's foreign exchange market structure is lack of liquidity. The transformation of trading arrangements, which brings a diversified market liquidity provision mechanism and increases the probability of deal making, is thus the most important move among all the reform measures to boost market liquidity.

Price discovery and exchange rate formation mechanism

Another important role of a market maker is price discovery. The introduction of market makers and quote-driven dealer markets in the spot market where the RMB against foreign currency pairs are traded plays a direct and central role in the determination of the RMB exchange rate. After the new trading arrangement was put into practice, the way of determination of the RMB central rate was changed from being determined by previous day's closing rate formed in the inter-bank spot market to being determined by the weighted average of the prices quoted by 13 market makers consisting of both local banks and foreign

banks. However, it should be duly observed that the price discovery function of market makers in China's foreign exchange market is still rather limited. There still exists a narrow floating band prescribed by the central bank and regulators also regulate market makers' net open foreign exchange positions²⁸ (both gross aggregated positions and single currency positions) to limit their scope of price discovery.

Central bank's control of the foreign exchange market

As already mentioned, before the market making system came into being, the central bank was the largest de facto "market maker" in China's foreign exchange market. Under the strong RMB appreciation pressure, the central bank had to frequently and passively absorb excess supply of US dollar to clear the market and maintain the US peg. This leads to a variety of problems including lack of independency and flexibility in administering monetary policy. Assigning market making responsibilities to commercial banks gives the central bank a way out of this vicious circle and allows the central bank more freedom in tackling problems at home and experimenting with new open market operations such as currency swaps. With the transformation in the trading arrangements also comes the central bank's adjustment in its way of controlling the foreign exchange market. Market makers will inevitably take over at least part of the information processing and price discovery function. The Chinese authorities have clearly stated its standpoint in not yielding to political pressures by making any one-off exchange rate adjustment (Wen, 2006²⁹). Thus continuing to breathe more latitude and more market forces into the exchange rate determination mechanism and as a result allowing more room for a gradual appreciation in the RMB/USD exchange rate is an expedient way of coping with political pressures from the international society.

2.3.4 Capital account liberalization

The current wave of loosening capital control has been prodded by the RMB appreciation pressure as well as the need to support domestic enterprises' overseas development. Controls have been eased mainly on three fronts:

First, allow domestic enterprises, financial institutions and individuals greater flexibility in retaining, acquiring and investing foreign exchange assets. For domestic resident individuals, controls on purchase of foreign exchange have been relaxed and a yearly quota equivalent to

²⁸ Market makers can't hold short positions in US dollar.

²⁹ This was clearly stated when Premier Wen addressed the press after the 4th session of the 10th National People's Congress.

US\$20,000 (up limit) in value will be adopted as of April 2006; for financial institutions, foreign exchange working positions have been enlarged in scope and in scale (September 2005); for domestic enterprises, in that they have been allowed to retain foreign exchange earnings in their foreign exchange accounts for current account transactions up to a limit equivalent to the sum of 80% of the current account receipts and 50% of the current account payments recorded in the previous year (August 2005).

Second, support domestic enterprises to invest and finance overseas. Rules to encourage domestic financial institutions' provision of financing guarantees for domestic enterprises investing overseas came into effect in September 2005. Shortly afterwards in October 2005, domestic residents (including enterprises and individuals) were permitted to establish or control offshore special purpose vehicles (SPV)³⁰ for equity financing and to return investment of proceeds. In April 2006, domestic residents' foreign exchange investment channels were further broadened by the new regulation which enabled them to invest in financial products overseas through domestic commercial banks. The Qualified Domestic Institutional Investors (QDII) system is also around the corner which will give domestic banks, insurance companies, fund management companies and security companies a chance to invest in overseas capital markets.

Third, encourage foreign capital's participation in the domestic capital market. The Current Qualified Foreign Institutional Investors (QFII)' investment quota has been enlarged and restrictions on foreign institutions and enterprises' financing activities in the domestic capital market have been gradually removed, granting them the right to issue RMB denominated bonds or become listed in the domestic capital market, possibly through the Chinese Depository Receipt³¹ (CDR).

Capital account liberalization moves will help create the demand for foreign currencies and rebalance supply and demand in the foreign exchange market and in turn increase market activity. Cross-border capital outflows and inflows, facilitated by foreign and domestic enterprises/institutions' ability to operate in both the domestic and overseas financial markets

³⁰ The SPV is usually a subsidiary company with an asset/liability structure and legal status that makes its obligations secure even if the parent company goes bankrupt. SPV's operations are limited to the acquisition and financing of specific assets

³¹ The Depository receipt is a negotiable financial instrument issued by a bank to represent a foreign company's publicly traded securities and can be traded on a local stock exchange.

as well as foreign banks' strong presence in China's foreign exchange market, can be expected to increase in frequency and volume. As a result, the domestic foreign exchange market will no longer be immune from new information and exchange rate movements born in overseas markets. On the other hand, recent policy initiatives have addressed some of the structural problems in the FX market and are expected to increase market liquidity, enhance market functions and influence exchange rate formation mechanisms. The rapid development of the domestic onshore foreign exchange market will make it more competitive in its race with the offshore market in terms of drawing liquidity and playing a leading role in price discovery. Thus mutual influences and further integration of the domestic foreign exchange market with international foreign exchange market should be anticipated.

2.4 RMB NDF market: development and characteristics

2.4.1 RMB NDF market

Non-deliverable forwards or NDFs represent forward foreign exchange transactions where there is no actual delivery of the contracted currency (which is usually an emerging market currency with limited convertibility) on the settlement date. The only exchange that occurs on the value date is the difference in the US dollar value (or other convertible currency) between the NDF contracted forward rate set on the trade date and the prevailing spot reference rate or fixing rate. The NDF market is categorized as an offshore market since it trades outside the direct jurisdiction of the authorities of the corresponding currencies and their pricing need not be constrained by domestic interest rates. The NDF market offers an alternative hedging tool for foreign investors with local currency exposure or a speculative instrument for them to take positions offshore in the local currency. The market activity in many Asian NDF markets in part reflects absence of or restricted access to domestic forward markets.

A Non-deliverable forward (NDF) market for the Chinese currency—RMB, inconvertible under capital account, emerged in Hong Kong and Singapore in 1995 and has become a highly liquid market since 2002 due to active speculation on the appreciation of the RMB. With an estimated average daily turnover of only \$ 50 million in June 2001 (Lehman Brothers), the RMB NDF market has become a much deeper market over the years with a daily turnover reaching \$ 200 million in early 2003 (Ma, 2004). However, the total volume of RMB NDF contracts only accounts for about 6% of the total NDF market volume³². Market

³² See Emerging Market Trade Association 2003 NDF Market Volume Survey which can be found on EMTA's website: www.emta.org.

liquidity has also improved with bid-ask spreads of 0.05-0.07 for a one-month contract and 0.12-0.18 for a one-year contract, much smaller than other Asian NDFs³³ and only larger than that for New Taiwan Dollar. The RMB NDF rate had been traded at premium³⁴ with respect to its spot fixing rate during and after the Asian crisis reflecting the depreciation pressure on the Chinese currency but the trend was reversed after late 2002 towards discount, with increasing expectations of a strengthening of the RMB and of a regime change leading to revaluation. The volatility of the RMB NDF rate is higher than the spot rate and tends to be larger for longer maturities (see table 2.5).

Table 2.5: Standard deviation of the RMB NDF and the spot daily closing rate, January 1, 1999 to March 30, 2006

Daily closing rate	Standard Deviation
1-month NDF	0.07
3-month NDF	0.11
6-month NDF	0.19
12-month NDF	0.37
Onshore Spot	0.06

Source: Reuters.

In earlier years, major participants in the RMB NDF market were multinationals who needed to hedge currency exposure associated with their foreign direct investment. But hedge funds have more recently assumed a more important role due to heightened speculation. It has been estimated that much of the volume in the RMB NDF is generated by speculative positioning while only a small proportion of customer demand for NDFs is currently based on FDI related hedging interests (Lipscomb, 2005). Besides, the NDF market has also served part of domestic enterprises' foreign exchange investment needs³⁵ due to lack of an onshore forward market until August 2005.

³³ Including Indian rupee, Indonesian rupiah, Korean won and Philippine peso.

³⁴ Premium is the amount by which a forward rate exceeds a spot rate while discount is the amount by which a forward rate is below a spot rate. Here RMB/USD exchange rate is quoted by stating the number of units of RMB that can be bought in terms of 1 unit of USD (direct quotation), so a RMB NDF contract trading at premium reflects the market's expectation of RMB depreciation in the future while a RMB NDF contract trading at discount reflects the expectation of RMB appreciation.

³⁵ Even though illegal, there're evidences that large domestic banks have been engaged in offering NDF products to their big corporate clients.

2.4.2 Differences and connections between the NDF market and the onshore foreign exchange market

Trading the same underlying currency, the NDF market and onshore spot market seem to have a natural bond which is only strengthened by the settlement rules of NDF products.

According to the terms of an NDF contract, if on the settlement date, the then-prevailing spot market exchange rate is greater (in foreign currency per dollar terms) than the previously agreed forward exchange rate, the holder of the contract who is long the emerging market currency must pay the holder of the other side of the contract the difference between the contracted forward price and the spot market rate. The settlement exchange rate is determined by a daily-posted rate (usually posted to a specific Reuters or Telerate screen), referred to as the “fixing rate”, which is generally based on the spot rate traded for the currency onshore. Thus the onshore spot rate is part of the formation of the final NDF settlement rate and will obviously exert influence over the NDF rate.

Information flows and transmission of prices and volatility between two financial markets trading similar products are normal. In the absence of capital control, arbitrage between two markets will also lead to convergence in prices. But in the case of the RMB onshore market and offshore NDF market, there're still many differences with respect to pricing and market functions. First, there's capital control in place. Ma (2004) found a large difference between the onshore interest rate and the NDF market's implied interest rate³⁶, indicating existence of strict capital control. Second, the pricing mechanism of the RMB NDF market may cause the NDF rate changes to deviate from onshore rate changes. The pricing of most forward foreign exchange contracts is primarily based on the interest rate parity relationship which ties the premium (discount) to the interest rate gap between the two currencies. But NDF prices can also be affected by the perceived probability of changes in the foreign exchange regime, speculative positioning, conditions in local onshore interest rate markets and the relationship between the offshore and onshore currency forward markets. Lipscomb (2005) argued that the NDF prices for RMB are based primarily on the expected future level of the spot exchange rate rather than interest rate parity calculations since offshore participants have very limited access to onshore RMB interest rate products. Third, these two markets target different market

³⁶ This rate is calculated as: $NDF = S(1+i)/(1+r^S)$, where NDF refers to the NDF rate, S is the prevailing interest rate in the domestic money market (for China, Chibor is used); r^S is the US Dollar LIBOR and i is the NDF implied offshore yield. A large and persistent onshore/offshore spread ($r - i$) indicates the presence of effective cross-border restrictions.

participants. The NDF market is mainly participated by multinationals and hedge funds with little market entry barriers while the onshore market is still much more regulated and restricted in market entry with trade being dominated by state-owned banks. Thus, it's reasonable to expect much less speculation and in turn volatility in the onshore spot market than in the NDF market.

Generally speaking, the relationship between the onshore spot market and the NDF market will be enhanced after the new reforms in the foreign exchange market and the liberalization of the capital account, even though existence of capital control and limited participation by offshore players in the domestic money market can still effectively diminish across-market arbitrage activities and hinder the rapid integration of the two markets. Lipscomb (2005) observed that in countries where regulations permit greater access for local entities to the offshore NDF markets, and offshore entities greater access to onshore markets, NDF prices will affect and be affected by local market prices, while for countries where cross-border market access is more limited, NDF prices will reflect primarily offshore supply and demand factors and have limited ability to influence onshore market. This coincides with evidence from Korea prior to the 1997 reform offered by Park (2001) which shows that the onshore market seems to lead the offshore market in this period.

3. Mean and Volatility spillover effects between RMB NDF and onshore spot market

3.1 Methodology

In this part of the empirical study of mean and volatility spillover effects between the RMB NDF market and onshore spot market, methods used will include an ADF unit root test testing for non-stationarity and a bivariate test of stationarity of the times series in the dataset, the Johansen co-integration test, the Johansen test of weak exogeneity and Granger causality test as well as ARCH and GARCH models to capture heteroscedasticity and investigate inter-market mean and volatility spillover effects. In this section, we'll briefly review the concept of co-integration and the ARCH/GARCH family of statistical models.

3.1.1 Co-integration

The concept of co-integration, formally introduced by the work of Granger (1983) and Engle and Granger (1987), is very important since it describes the existence of an equilibrium or stationary relationship among two or more time-series, each of which is individually non-stationary. Consider a vector time series of dimension n , $x_t = (x_{1t}, x_{2t}, \dots, x_{nt})'$ where x_t is $I(1)$, i.e. non-stationary with a unit root so that Δx_t is $I(0)$, i.e. stationary. If there exist a vector α_i such that, $w_t = \alpha_i' x_t \sim I(0), i = 1, 2, \dots, r$ then the relevant components of x_t are said to be co-integrated (see Banerjee et al., 1993).

The methodology proposed by Johansen (1988) tests the number of co-integrating relationships in systems of equations and can be adapted to indicate the direction of causality. This method is based on a p -dimensional VAR of order k for all variables in a given information set. An important property characterizing co-integrated variables is that they are known to have, among other representations, an error-correction representation (*Granger's Representation Theorem*). Let the error-correction representation be expressed as:

$$(3.1) \Delta y_t = \mu + \pi y_{t-1} + \sum_{i=1}^{k-1} \delta_i \Delta y_{t-i} + \gamma D_t + \varepsilon_t, \varepsilon_t \sim IID(0, \Sigma)$$

where $t=1, \dots, T$, y_t is the $n \times 1$ vector consisting of the model endogenous $I(1)$ variables, D_t contains deterministic components as centered seasonal dummies and $I(0)$ variables conditional upon in the analysis. μ is a vector of constants. The rank of the coefficient matrix π for the lagged level variables y_{t-1} yields the number of co-integrating relationships. There are three distinct cases regarding the rank of π , (i) $r = n$, (ii) $r = 0$, and (iii) $0 < r < n$. If (i) or full rank of π applies, then all the variables in y_t are stationary; if (ii) is true, then there's no co-integration between the variables in y_t and all variables become non-stationary; if (iii) is the case, then we have a co-integrated system with r co-integrating vectors. In this case, π can be expressed as the product of a $n \times r$ loading matrix α and $r \times n$ co-integrating vector matrix β' where the rows in β' are the co-integrating vectors and the columns in α the adjustment coefficients or feedback coefficients which measure the degree of error correction in the individual equations of the system.

3.1.2 ARCH and GARCH models

It's a stylized fact that foreign exchange rates and rate changes (first differences) are characterized by "volatility clustering" (Melvin, 2003). This has led to the application of ARCH (Autoregressive Conditional Heteroscedasticity) and GARCH (Generalized Autoregressive Conditional Heteroscedasticity) models in describing the volatility of financial time series.

"Volatility clustering" is a phenomenon that large price changes tend to be followed by large changes and small changes tend to be followed by small changes (Mandelbrot, 1963; Fama, 1965), indicating that the error term of an autoregressive process with a constant unconditional variance could have a time varying conditional variance. An autoregressive conditional heteroscedastic (ARCH) model to capture the effect of this changing volatility introduced by Engle (1982) takes the following form:

$$(3.2.1) \quad y_t = c + x_t' \beta + u_t, \quad u_t = h_t^{1/2} v_t, \quad v_t \sim IID(0,1)$$

$$(3.2.2) \quad h_t = \zeta + \sum_{i=1}^q \alpha_i u_{t-i}^2 = E(u_t^2 | u_{t-1}, u_{t-2}, \dots)$$

where h_t is the conditional variance, x_t is a vector containing lags of the dependent variable, exogenous variables conditioned upon in the analysis or the conditional variance term h_t ,

$$\zeta > 0, \alpha_i \geq 0, \text{ and } \sum_{i=1}^q \alpha_i < 1 (i=1, \dots, q).$$

A white noise process u_t satisfying (3.2.1) and (3.2.2) is described as an ARCH process of order q , denoted $u_t \sim ARCH(q)$.

If x_t contains the conditional variance term h_t then we will arrive at an ARCH-in-mean model introduced by Engle, Lilien and Robin (1987) to capture the effect that higher perceived variability in u_t has on the level of y_t ³⁷.

The ARCH model which didn't allow the conditional variance at time t to have a stochastic component was extended by Bollerslev (1986) to become a generalized conditional heteroscedasticity (GARCH) model. The GARCH model can be formulated as follows,

$$(3.3.1) \quad y_t = c + x_t' \beta + u_t, \quad u_t = h_t^{1/2} v_t, \quad v_t \sim IID(0,1)$$

$$(3.3.2) \quad h_t = \zeta + \sum_{i=1}^q \alpha_i u_{t-i}^2 + \sum_{i=1}^p \beta_i h_{t-i}$$

where h_t is the conditional variance, x_t is a vector containing lags of the dependent variable, exogenous variables conditioned upon in the analysis or the conditional variance term h_t ,

$$\zeta > 0, \alpha_i \geq 0 (i=1, \dots, q), \text{ and } \beta_i \geq 0 (i=1, \dots, p) \text{ and } \sum_{i=1}^q \alpha_i + \sum_{i=1}^p \beta_i < 1.$$

The GARCH model can then encompass all ARCH versions as an ARCH (q) model can be specified as a GARCH (0, q) model. Let the x_t be a vector containing lags of the dependent variable and rewrite (3.2.1) below:

³⁷ As suggested in Finance theory, an asset with higher perceived risk would pay a higher average return (Hamilton, 1994).

$$(3.4) \quad y_t = c + \sum_{i=1}^m \phi_i y_{t-i} + u_t, \quad u_t = h_t^{1/2} v_t, \quad v_t \sim IID(0,1)$$

(3.4) together with (3.3.2) constitute an AR (m)-GARCH (p, q) used later in the thesis.

A situation where $\sum_{i=1}^q \alpha_i + \sum_{i=1}^p \beta_i = 1$ is referred to as an integrated GARCH process, or

IGARCH. An error term u_t following an IGARCH process has infinite unconditional variance, or in other words, the volatility of a series is permanently affected by any shocks (Engle and Bollerslev, 1986). Then neither u_t nor u_t^2 satisfies the definition of covariance-stationary, however, there's still a possibility that u_t comes from a strictly stationary process (see Nelson, 1991).

Finally, a GARCH_t model which will be utilized in the later sections of the thesis means a GARCH with student t-distributed rather than normally distributed errors. Estimation of the ARCH/GARCH models is usually realized by maximizing the likelihood function using numerical techniques based on the Berndt-Hall-Hall-Hausman (BHHH) algorithm.

Under the ARCH/GARCH framework, the mean and volatility effects from market i to market j can be easily tested by including the mean and conditional variance from market i as exogenous variables in market j's mean and conditional variance equations respectively and exploring the significance level of relevant coefficients.

3.2 Data, integration and descriptive statistics

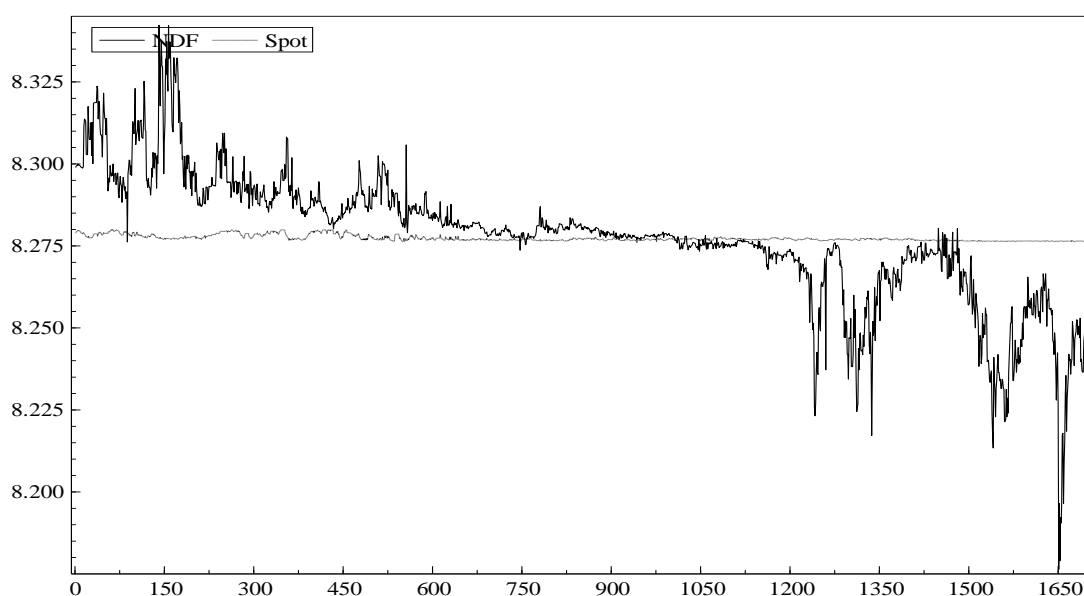
3.2.1 Data and preliminary graphs

The data employed in this thesis consist of daily RMB-US Dollar closing rates of the one-month NDF in the RMB NDF market and RMB spot in the onshore spot market. Both the spot rate and NDF rate data are obtained from REUTERS.

The data period starts January 1, 1999 and ends March 30, 2006. Since there was a regime change in July 21, 2005 when China abandoned the *de facto* US Dollar peg and opted for a reference to a basket peg, we could go a step further to divide the whole dataset into two periods: the pre-reform period covering the time span from January 1, 1999 to July 20, 2005 and the post-reform period covering the time span from July 21, 2005 to March 30, 2006. By

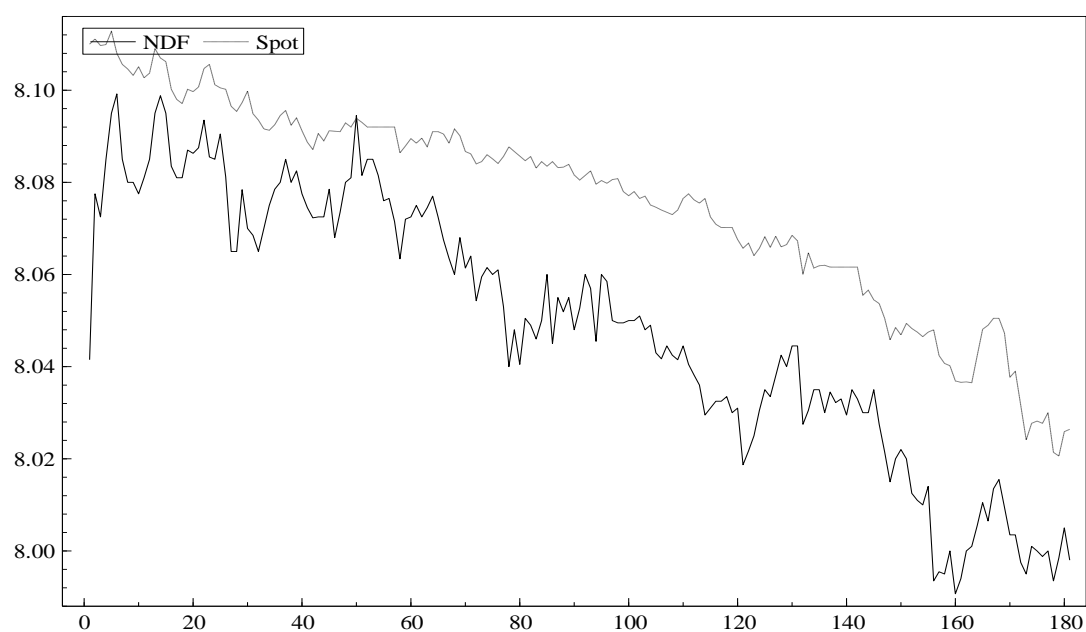
this division, we'll be able to look at the impact of the reform on the exchange rate behavior and the two markets dynamics. Both the pre-reform and post-reform periods will be studied in the preliminary analysis but only the post-reform period will be the focus of research in subsequent analyses.

Figure 3.1: Level NDF and Spot closing rates, pre-reform period, Jan.1, 1999-Jul.20, 2005



Source: Reuters.

Figure 3.2: Level NDF and Spot closing rates, post-reform period, Jul.21, 2005-Mar.30, 2006



Source: Reuters.

From figure 3.1, it can be seen that the RMB spot exchange rate curve is almost flat before the July 21 reform, which is not surprising since in that period, China's exchange rate was pegged to US Dollar and the floating band was further narrowed after the Asian Financial Crisis. The central bank had to frequently intervene in the onshore foreign exchange market to maintain the peg which resulted in a "super stable" RMB-US Dollar rate over the pre-reform period. Considering the virtually fixed spot rate, the pre-reform structural and institutional features of China's onshore foreign exchange market discussed above and the existence of capital control, it's reasonable to expect little information flows between the onshore spot market and the offshore NDF market in this period. Thus we will conduct ADF unit root tests and review the basic statistics describing exchange rate movements for both periods below and preclude the pre-reform period from our analyses thereafter.

3.2.2 ADF unit root test

Prior to time-series modeling, it is necessary to determine the orders of integration for the variables in the dataset. Below we therefore first present the results from using augmented Dickey-Fuller tests with a constant to test for unit roots in individual time series (Dickey and Fuller, 1981).

The ADF test is a common approach for testing non-stationarity in time series. When y_t follows the AR (p) process in 3.5, the ADF unit root test can be constructed with the regression model in 3.6.

$$(3.5) \quad y_t = \sum_{i=1}^p \rho_i y_{t-i} + \varepsilon_t$$

$$(3.6) \quad y_t = \rho y_{t-1} + \sum_{i=1}^{p-1} \gamma_i \Delta y_{t-i} + u_t$$

If the null hypothesis that $\rho=1$ is true, then y_t is a random walk and if the null hypothesis is false, then y_t is stationary. The results from a test based on a t-statistic of the form $(\hat{\rho}-1)/SE(\hat{\rho})$ are reported in table 3.1.

Table 3.1: ADF (4) Statistics for Testing for a Unit Root

Variable	Critical Values	Null Hypothesis	
		I (1)	I (2)
<i>Pre-reform period (Sample size: 1709)</i>			
NDF	5%=-2.86	-2.44	-22.20**
	1%=-3.44		
Spot	5%=-2.86	-4.95**	-20.44**
	1%=-3.44		
<i>Post-reform period (Sample size: 181)</i>			
NDF	5%=-2.88	-0.74	-8.35**
	1%=-3.47		
Spot	5%=-2.88	0.19	-7.25**
	1%=-3.47		

Notes:

1. For a null hypothesis of I (1), the ADF (4) statistic is testing a null hypothesis of a unit root in the levels of the variable y_t against the alternative of a stationary root. For a null hypothesis of I (2), the ADF (4) statistic is testing a null hypothesis of a unit root in the first differences of the variable Δy_t against the alternative of a stationary root.
2. A constant term is included the corresponding regressions.
3. Here and elsewhere in the thesis, asterisk * and ** denote the rejection of the null hypotheses at the 5% and 1% significance level respectively.

From table 3.1, it can be seen that the null of a non-stationary NDF rate can't be rejected to a level below 5% in neither the pre-reform or post-reform period while that for Spot can be rejected in the pre-reform period but not in the post-reform period, indicating that the spot rate becomes non-stationary after the July 21 reform. These findings echoes what we can see from figure 3.1 and 3.2 and reflects the fact that more flexibility and in turn more volatility in the spot rate behavior, were introduced after the reform in the RMB exchange rate regime.

The non-stationarity found in both periods, however, disappears after the first differences are taken, as can be seen from table 3.1 and the fact that ΔNDF and $\Delta Spot$ are stationary in both periods. According to the ADF unit root tests, both NDF and Spot variables appear to be integrated of order one in the post reform period. As a result, $\Delta NDF = NDF_t - NDF_{t-1}$ and $\Delta Spot = Spot_t - Spot_{t-1}$ will be used for most of the following analyses except the co-integration test.

The above ADF test is a univariate test for stationarity in time series. Later in the thesis another test for stationarity using the Johansen method in a multivariate framework will also be presented together with a discussion of the differences between the two tests for stationarity and a comparison of the results.

3.2.3 Summary statistics

Table 3.2 below reports the descriptive statistics for the first differences of the NDF and Spot rate in both the pre-reform and post-reform period.

Table 3.2 Summary statistics for spot and NDF rate changes

Variable	Mean	Standard deviation	Skewness	Excess kurtosis	Normality test $\chi^2(2)$	L-B Q (10)	L-B $Q^2(10)$
<i>Pre-reform period</i>							
ΔNDF	-4.4614e-005	0.0048	-0.315	16.008	2983.0 (0.00)	110.89 (0.00)	303.95 (0.00)
$\Delta Spot$	-1.4052e-006	0.0002	0.298	4.797	620.52 (0.00)	70.08 (0.00)	354.20 (0.00)
<i>Post-reform period</i>							
ΔNDF	-0.0002	0.0066	0.5578	4.5602	65.188 (0.00)	16.75 (0.08)	2.63 (0.99)
$\Delta Spot$	-0.0005	0.0025	-0.6229	1.6569	14.492 (0.00)	18.53 (0.04)	40.56 (0.00)

Note: P-values are in parentheses.

From table 3.2, negative means are observed for changes in NDF and spot rates across the whole sample period from 1999 to 2006, indicating the appreciation pressure on the Chinese currency. Average exchange rate changes are larger in the post-reform period than in the pre-reform period. Standard deviations for both ΔNDF and $\Delta Spot$ have larger values in the post-reform period than in the pre-reform period, exhibiting an increase in volatility after the reform. In particular, the magnitude of increase in $\Delta Spot$ (0.0023) is larger than that in ΔNDF (0.0018), reflecting the central bank's stronger control over the spot exchange rate under the previously "fixed" exchange rate regime and the effect that the regime change had on central bank's way of control and market participants' behavior. In general, the volatility in the offshore market is higher than in the onshore spot market, which is quite evident considering the strong presence of speculative activities in the offshore market. Distribution properties of

the NDF and spot rate are also examined in table 3.2 with a null hypothesis that both series have a normal distribution. A normal distribution would have Skewness around zero and Kurtosis of three (Skewness and Kurtosis are defined in (A.2.1) and (A.2.2) in Appendix 2). Thus both series are skewed and leptokurtic in both periods. The null hypothesis of a normal distribution is rejected by the normality test based on Doornik and Hansen (1994). The null hypothesis for the Ljung-Box statistic is that all serial correlation of ΔNDF ($\Delta Spot$) up to lag 10 are jointly zero. The H_0 is clearly rejected for both ΔNDF and $\Delta Spot$ in both periods in figure 3.2, showing strong autocorrelation in both series. The Ljung-Box $Q^2(10)$ statistic for $\Delta Spot$ is also strongly significant, indicating the presence of serial correlation in squared series of $\Delta Spot$ suggesting the existence of autoregressive conditional heteroscedasticity in the noise process.

3.3 Co-integration and causality

Co-integration in system of equations has been reviewed in the methodology section of this thesis and here Johansen co-integration tests will be applied to our dataset in order to identify the long-run relationships and the direction of causality between NDF and spot rates in the post-reform period. A bivariate test for stationarity and the Granger causality test will also be included.

3.3.1 Johansen co-integration test

Since the co-integration method in the thesis is based on a vector autoregression of order k for both variables in the dataset and this order is not known *a priori*, preliminary testing of the lag order is appropriate. Starting with a VAR of order five, both the individual equation and system diagnostics are reported as in table 3.3 and 3.4.

Table 3.3: Single equation diagnostics for the unrestricted VAR

Equation	AR 1-2 test F(2,163)	ARCH 1-1 test F(1,163)	Hetero test F(20,144)	Hetero-X test F(65,99)	Normality test $\chi^2(2)$
NDF	1.1118 [0.3314]	0.0180 [0.8935]	0.5325 [0.9487]	0.5055 [0.9981]	6.4977 [0.0388]*
Spot	0.5797 [0.5612]	2.5003 [0.1158]	1.52 [0.0828]	1.175 [0.2322]	15.996 [0.0003]**

Notes:

1. The significance probability for F statistic and χ^2 test is reported in square brackets.
2. Doornik and Hendry (2001) argue that it is usually unwise to force the constant to lie in the co-integration space. A test has been conducted to decide whether the constant should be restricted or left unrestricted when estimating the unrestricted reduced form system in this thesis. We constructed an error correction model where the co-integrating relation included a restrictedly estimated constant. Then the constant term of the error correction model was set equal to zero. The rejection of this zero restriction to a level of close to one percent indicates that when specifying the VAR the constant should not be restricted to lie in the co-integration space.

Table 3.4: Vector test diagnostics for the unrestricted VAR

AR 1-2 test F(8,320)	Hetero test F(60,424)	Hetero-X test F(195,291)	Normality test $\chi^2(4)$	Skewness	Excess Kurtosis
1.1908 [0.3038]	1.0330 [0.4147]	0.8221 [0.9300]	27.889 [0.0000]**	-0.4725 -0.5106	4.3206 4.8006

Notes:

1. The significance probability for F statistic and χ^2 test is reported in square brackets.

All statistics are fine in table 3.3 and 3.4 except those for normality. The null hypotheses of normality were rejected for both the single equation and system diagnostics. A closer look at the last two columns in table 3.4 suggests, however, that the normality anomaly may be due to large values of excess kurtosis and thus should not seriously contribute to jeopardize the results of the co-integration analysis (see Gonzalo 1994).

In order to determine the appropriate order of the VAR for the co-integration analysis, a general to specific approach is adopted starting with a VAR of order five. Now we can seek sequential reduction in the system by deleting the fifth lags of both the NDF and Spot rate, re-estimating the system and checking the information criteria and F-form statistic for the validity of the reduction. If the reduction is valid then a further deletion of the fourth lags will be carried out and so forth. It can be shown in table A.1.1 (see Appendix 1) that it is statistically acceptable to simplify the VAR to an order of two. SC and AIC criteria continue

to improve with null hypothesis not rejected from VAR (5) all the way down to VAR (2) but not further to a VAR of order 1, suggesting the appropriate VAR order to be equal to two.

With the order determined, the Johansen co-integration test can be performed with the results implying the number of co-integrating vectors reported in table 3.5 below.

Table 3.5 Johansen Co-integration Test

System: $Y_t = \begin{pmatrix} NDF_t \\ Spot_t \end{pmatrix}$		
Model: $\begin{pmatrix} \Delta NDF_t \\ \Delta Spot_t \end{pmatrix} = \begin{pmatrix} d_{11} & d_{12} \\ d_{21} & d_{22} \end{pmatrix} \begin{pmatrix} \Delta NDF_{t-1} \\ \Delta Spot_{t-1} \end{pmatrix} + \begin{pmatrix} \pi_{11} & \pi_{12} \\ \pi_{21} & \pi_{22} \end{pmatrix} \begin{pmatrix} NDF_{t-1} \\ Spot_{t-1} \end{pmatrix} + \begin{pmatrix} e_{1t} \\ e_{2t} \end{pmatrix}, \pi = \begin{pmatrix} \pi_{11} & \pi_{12} \\ \pi_{21} & \pi_{22} \end{pmatrix} = \alpha \beta'$		
VAR order: 2, unrestricted constant.		
Sample period: July 21, 2005 to March 30, 2006 (post-reform period).		
Eigenvalues: $\lambda_1=0.0897$ $\lambda_2=9.6768e-005$		
Trace eigenvalue test		
H_0	H_1	Test values
r=0	r=2	16.847 [0.029] *
r=1	r=2	0.017 [0.895]

Notes:

1. r denotes the rank of the π matrix.
2. p-value is reported in square brackets.
3. Trace test is likelihood test defined by $-2 \ln Q = -T \sum_{i=t+1}^p \ln(1 - \hat{\lambda}_i)$.

The null hypothesis of rank r is tested against the alternative hypothesis of full rank. From Table 3.5, it can be seen that the null of a rank equal to zero is rejected to a significance level below 5% while the null of a rank equal to one can't be rejected. Thus we'll be able to identify one co-integrating relationship between the two I (1) series, NDF and Spot, supporting the existence of a long-run equilibrium relation between the RMB-US Dollar NDF and onshore spot rates. The eigenvector and adjustment coefficient vector are presented below in 3.7 and 3.8.

(3.7) Normalized eigenvectors $\beta' = (1.0000, -1.2558)$

(3.8) Adjustment coefficient (feedback coefficients) $\alpha = \begin{pmatrix} -0.1656 \\ 0.0259 \end{pmatrix}$

The adjustment coefficient vector α is significantly estimated and correctly signed in the sense that if the NDF and SPOT rates are higher than those implied by the co-integrating relationship and thus produce an error, this error will contribute to a lowering of the NDF and SPOT rate respectively.

The linear combination (by restricting the co-integrating rank to one but with no additional restrictions) as well as the LR test for a homogeneity restriction on the co-integrating vector is displayed in table 3.6.

Table 3.6: Co-integrating linear combination and tests of $\beta' = (1, -1)'$ restriction

The unrestricted co-integrating linear combination:	
$\beta' \begin{pmatrix} NDF_t \\ Spot_t \end{pmatrix} = \text{NDF} - 1.2558 \text{ Spot}$ <div style="text-align: center; margin-left: 150px;">(0.090)</div>	
Hypothesis:	LR-test, Rank=1
$\beta_1 = -\beta_2$	5.7496 [0.0165]*

Notes:

The value shown in the parenthesis below the coefficient of the co-integrating vector is the standard error of the coefficient.

The rank one LR-test result clearly rejected the hypothesis of $\beta_1 = -\beta_2$ or a homogeneity restriction on the co-integrating vector, precluding the possibility of a co-integrating linear combination of the form: $\beta' \begin{pmatrix} NDF_t \\ Spot_t \end{pmatrix} = \text{NDF} - \text{Spot}$.

Restrictions on the co-integrating vector also enable us to carry out multivariate tests for stationarity.

3.3.2 Multivariate test for stationarity

Multivariate tests for stationarity and the univariate ADF test discussed above differ in two important ways. First, when using the multivariate test for stationarity under the Johansen framework, the null hypothesis is that the individual time series is stationary while when using the ADF test, the null hypothesis is the existence of a unit root and thus non-stationarity. Second, the multivariate test statistics may have higher finite sample power than

the univariate test and are believed to yield more reliable results (see De Brouwer and Ericsson, 1995).

By testing the restriction that the co-integrating vector contains all zeros except for a unity corresponding to the designated variable, we'll be able to test the stationarity of the individual time series. A co-integrating relationship has been identified between the two I(1) variables NDF and Spot, a certain linear combination of them results therefore in a stationary process. Thus restricting the co-integrating vector to take the form of $(1, 0)'$ leads to the null hypothesis of a stationary NDF series while a co-integrating vector equal to $(0, 1)'$ would imply a null of a stationary Spot series. The $\chi^2(1)$ statistics in table 3.7 show that both of these null hypotheses are rejected, which points to the non-stationarity of both series. This result is consistent with our findings in the ADF test.

Table 3.7: Multivariate statistics for testing stationarity

Variable	NDF	Spot
Test conditional on one co-integrating vector $\chi^2(1)$	15.820	16.785
	[0.0001]**	[0.0000]**

Notes:

P-value is shown in square brackets.

3.3.3 Causality

After a long-run equilibrium relationship has been found, it will also be interesting to look at the implied causality of the co-integration analysis as the presence of error correction contains important clues to the direction of information flow between the offshore NDF market and the onshore spot market. To help with this a simple test of weak exogeneity proposed by Johansen (1992a, 1992b) will be employed first followed by a Granger causality test³⁸.

Johansen's test of weak exogeneity

This test consists of a test of zero restrictions on a subset of the adjustment coefficients in the loading matrix α (the error correction coefficients). Let's consider an error correction version of the system under analysis as follow,

³⁸ Johansen's test of weak exogeneity tests whether there's any feedback from the error correction term to the variable under analysis, the Granger causality test, on the other hand, is a joint test of both the feedback effects through error correction and the dynamic short run lagged effects through the model endogenous variables. Thus the Johansen causality test is encompassed by the Granger causality test in this sense.

$$(3.9) \quad \Delta Y_t = D_1 \Delta Y_{t-1} + \alpha (NDF_{t-1} - 1.2558 Spot_{t-1}) + e_t$$

where $\Delta Y_t = \begin{pmatrix} \Delta NDF_t \\ \Delta Spot_t \end{pmatrix}$, $\Delta Y_{t-1} = \begin{pmatrix} \Delta NDF_{t-1} \\ \Delta Spot_{t-1} \end{pmatrix}$, $NDF_{t-1} - 1.2558 Spot_{t-1}$ is the error correction term

corresponding to $(\beta_1, \beta_2) \begin{pmatrix} NDF_{t-1} \\ Spot_{t-1} \end{pmatrix}$, $\alpha = \begin{pmatrix} -0.1656 \\ 0.0259 \end{pmatrix}$ and $e_t = \begin{pmatrix} e_{1t} \\ e_{2t} \end{pmatrix}$.

As a result, in the dataset under analysis, a null hypothesis of $\alpha_1 = 0$ means that the NDF rate does not error correct deviations from its long run relationship with the Spot rate or equivalently that the NDF rate is exogenous with respect to estimation of the long-run parameters; on the other hand, a null hypothesis of $\alpha_2 = 0$ means that it's the Spot rate that does not error correct and thus can be considered exogenous. Table 3.8 shows that the weak exogeneity of the NDF rate is rejected which suggests an error correction causality going from the onshore spot rate to the NDF rate. The weak exogeneity of the Spot rate on the other hand can't be rejected to a level below 5% which rules out an error correction causality going from the NDF rate to the spot rate.

Table 3.8: Tests of weak exogeneity

Hypothesis:	LR-test, Rank=1
$\alpha_1 = 0$	9.4920 [0.0021]**
$\alpha_2 = 0$	1.3234 [0.2500]

Notes:

LR test's p-value is shown in square brackets.

Granger causality test

If, in the universe of information, deleting the history of one set of variables does not alter the joint distribution of any of the remaining variables, then the omitted variables were defined by Granger (1969) not to cause the remaining variables (Hendry and Mizon, 1999). A bivariate VAR system can be used to explain the concept of Granger causality (Hamilton, 1994):

In a bivariate VAR describing x and y , y doesn't Granger-cause x if the coefficient matrices Φ_j are lower triangular for all j :

$$(3.10) \begin{bmatrix} x_t \\ y_t \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \end{bmatrix} + \begin{bmatrix} \phi_{11}^{(1)} & 0 \\ \phi_{21}^{(1)} & \phi_{22}^{(1)} \end{bmatrix} \begin{bmatrix} x_{t-1} \\ y_{t-1} \end{bmatrix} + \begin{bmatrix} \phi_{11}^{(2)} & 0 \\ \phi_{21}^{(2)} & \phi_{22}^{(2)} \end{bmatrix} \begin{bmatrix} x_{t-2} \\ y_{t-2} \end{bmatrix} + \dots + \begin{bmatrix} \phi_{11}^{(p)} & 0 \\ \phi_{21}^{(p)} & \phi_{22}^{(p)} \end{bmatrix} \begin{bmatrix} x_{t-p} \\ y_{t-p} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix}$$

Note: See Hamilton, James D. (1994): Time Series Analysis, Princeton, New Jersey: Princeton University Press: 303

An error correction model of the system can be constructed as in (3.10) and estimated unrestrictedly in order to perform the Granger causality test for the dataset under analysis. As can be seen in table 3.9, the tests for non-Granger-causality in the marginal processes of respectively NDF and Spot are both rejected. This yields evidence of a two-way causality. This result isn't in full accordance with the unidirectional causality found in Johansen's test of weak exogeneity but it's worth noting that the Granger causality test encompasses the Johansen causality test in the sense that in addition to test for the significance of error correction it tests for dynamic feedback effects through the lagged model endogenous variables.

Table 3.9: Granger causality test

Null Hypothesis	F-statistic	P-value
① Spot doesn't Granger cause NDF	4.7777 **	0.0095
② NDF doesn't Granger cause Spot	3.4980 *	0.0324

Notes:

Since a VAR of order two is used in our previous analysis, the Granger causality test is performed with two regressions. For test of the null hypothesis ①, we regress ΔNDF_t on ΔNDF_{t-1} , $\Delta Spot_{t-1}$ and the co-integration relationship lagged one period and conduct a F-test on the null hypothesis that the coefficients of $\Delta Spot_{t-1}$ and the co-integration relationship lagged one period are jointly zero. For test of the null hypothesis ②, we regress $\Delta Spot_t$ on $\Delta Spot_{t-1}$, ΔNDF_{t-1} and the co-integration relationship lagged one period and conduct a F-test on the null hypothesis that the coefficients of ΔNDF_{t-1} and the co-integration relationship lagged one period are jointly zero.

There exist many critiques of the Granger causality test and it might therefore be dangerous to infer the direction of true causation from this test alone. Nevertheless, this test remains useful in the sense that the result is simply reflecting the presence or absence of feedbacks in a limited dataset, irrespective of whether or not they are "genuine DGP causes" (Hendry and Mizon, 1999). This "presence or absence of feedbacks in a limited dataset" is exactly what we're interested in, so it's quite safe to say there're presences of feedbacks or information

flows in both directions between the offshore NDF market and the onshore spot market in the post-reform period based on the Granger causality test. Direction of spillover effects between the two markets will be further explored in the GARCH modeling section of this thesis and a rationale behind these findings are provided.

3.4 Spillover effects between NDF and spot markets

As mentioned in the introduction, the use of the ARCH/GARCH framework to describe exchange rate behavior and explore the mean and volatility contagion effects across different foreign exchange markets is pervasive in the literature. The ARCH/GARCH approach will also be adopted in this thesis to capture the conditional heteroscedasticity in the data sample³⁹ and test for potential spillover effects between the RMB NDF market and onshore spot market in the post-reform period. Model specification tests of a variety of models under the ARCH/GARCH framework have been tested on the dataset and the AR (1)-GARCH (1,1) and AR (1)-GARCH_t (1, 1) have been confirmed as the most parsimonious fit to the ΔNDF_t and $\Delta Spot_t$ series.

The AR (1)-GARCH (1, 1) model for NDF rate changes-- ΔNDF_t can be formulated by a set of mean and conditional variance equations as in (3.11.1) and (3.11.2):

$$(3.11.1) \quad \Delta NDF_t = c + \phi_t \Delta NDF_{t-1} + u_{it} \quad , \quad u_{it} = h_{it}^{1/2} v_{it} \quad , \quad v_{it} \sim IID(0,1)$$

$$(3.11.2) \quad h_{it} = \alpha_{i0} + \alpha_{i1} u_{it-1}^2 + \beta_{it} h_{it-1}$$

The AR (1)-GARCH (1, 1) with student t-distributed error model for Spot rate changes-- $\Delta Spot_t$ can be formulated as follows,

$$(3.12.1) \quad \Delta Spot_t = c + \phi_t \Delta Spot_{t-1} + u_{it} \quad , \quad u_{it} = h_{it}^{1/2} \varepsilon_{it} \quad , \quad \varepsilon_{it} | F_{t-1} \sim t[\nu]$$

$$(3.12.2) \quad h_{it} = \alpha_{i0} + \alpha_{i1} u_{it-1}^2 + \beta_{it} h_{it-1}$$

³⁹ The preliminary analysis of our dataset reported in section 3.3 has offered some clue of the presence of conditional heteroscedasticity as strong autocorrelation in the squares of the differenced series $\Delta Spot$ is found.

Estimation results of model (3.11.1)-(3.11.2) and (3.12.1)-(3.12.2) are shown in table 3.10 below, indicating no major misspecification. For model (3.12.1)-(3.12.2), the coefficients for the GARCH (1, 1) terms, α_{i1} and β_{it} , the student t-distributed error term and the AR (1) term are all statistically significant while for model (3.11.1)-(3.11.2), the insignificant GARCH (1, 1) coefficients may be due to the fact that most part of the heteroscedasticity in the series has been seized by the AR (1) term reflected in the strongly significant coefficient of that term.

With these results at hand, further steps can be taken to model the mean and volatility spillover effects. Contemporaneous mean spillover effects from the spot market to the NDF market can be represented by adding $\Delta Spot_t$ to equation (3.11.1) and volatility spillover effects can be modeled by including the squares residuals estimated from the AR (1)-GARCH_t (1, 1) model in equation (3.11.2). Similar operations will be able to examine contemporaneous mean and volatility spillover effects from the NDF market to the spot market. Equations (3.13.1)-(3.13.2) to (3.14.1)-(3.14.2) given below will articulate the methods.

Table 3.10: Estimates of AR (1)-GARCH (1, 1) and AR (1)-GARCH_t (1, 1) model

	ΔNDF_t		$\Delta Spot_t$	
	Coefficient	t-stat. (p-value in the brackets)	Coefficient	t-stat. (p-value in the brackets)
c	-0.0006	-1.33 (0.186)	-0.0004	-2.61 (0.010)
ϕ_i	-0.173	-2.50 (0.013)	-0.162	-2.03 (0.044)
α_{i0}	2.04881e-005	0.91 (0.363)	8.82698e-008	0.92 (0.361)
α_{i1}	0.111	1.29 (0.199)	0.079	2.27 (0.024)
β_{it}	0.307	0.469 (0.640)	0.918	33.3 (0.000)
Student-t df			5.64	2.78 (0.006)
Number of obs.	179		179	
Log-likelihood	664.752		837.25	
Normality test $\chi^2(2)$	6.0171 (0.05)		9.501 (0.0086)**	
Portmanteau(10)	11.990 (0.2139)		19.934 (0.0183)*	
Portmanteau ² (10)	4.677 (0.7915)		7.390 (0.4952)	

Note:

For $\Delta Spot_t$, $\alpha_{i1} + \beta_{it} = 0.9966$, which indicates an IGARCH model and thus a close to unit root in the variance process. Engle, ITO and Lin pointed out that this was indicative of shocks lasting forever but as argued by Nelson (1991), GARCH models including IGARCH models are in general strictly stationary. Thus modeling the spot rate changes by an IGARCH should neither pose a stability problem nor a balanced equation problem.

Spillover effects from the spot market to the NDF market:

$$(3.13.1) \Delta NDF_t = c_i + \phi_i \Delta NDF_{t-1} + \gamma_j \Delta Spot_t + u_{it}, u_{it} = h_{it}^{1/2} v_{it}, v_{it} \sim IID(0,1)$$

$$(3.13.2) h_{it} = \alpha_{i0} + \delta_j \hat{\sigma}_{jt}^2 + \alpha_{i1} u_{it-1}^2 + \beta_{it} h_{it-1}$$

Spillover effects from the NDF market to the spot market:

$$(3.14.1) \Delta Spot_t = c_j + \phi_j \Delta Spot_{t-1} + \gamma_i \Delta NDF_t + u_{jt}, u_{jt} = h_{jt}^{1/2} \varepsilon_{jt}, \varepsilon_{jt} | F_{t-1} \sim t[\nu]$$

$$(3.14.2) h_{jt} = \alpha_{j0} + \delta_i \hat{\sigma}_{it}^2 + \alpha_{j1} u_{jt-1}^2 + \beta_{jt} h_{jt-1}$$

where $\hat{\sigma}_{jt}^2$ is the squared residuals estimated from the AR (1)-GARCH_t (1, 1) model for

$\Delta Spot_t$ and $\hat{\sigma}_{it}^2$ is the squared residuals estimated from the AR(1) -GARCH (1, 1) model for ΔNDF_t . A subscript of i represents the NDF market and j symbolizes the spot market.

Thus a significant coefficient γ_j indicates mean spillover and δ_j volatility spillover from the spot market to the NDF market while the significance of γ_i and δ_i will be evidence of mean and volatility spillover from the NDF market to the spot market. Test results are derived in table 3.11.1 and 3.11.2.

Table 3.11.1: Mean and volatility spillover effects from the spot market to the NDF market

	Coefficient	t-statistic	p-value
c_i	-0.0001	-0.381	0.704
ϕ_i	-0.258	-3.36	0.001
γ_j	0.928	3.66	0.000
δ_j	-0.203	-0.88	0.380
α_{i0}	1.72663e-005	2.18	0.031
α_{i1}	0.259	1.25	0.214
β_{it}	0.213	0.64	0.522

Table 3.11.2: Mean and volatility spillover effects from the NDF market to the spot market

	Coefficient	t-statistic	p-value
c_j	-0.0003	-2.54	0.012
ϕ_j	-0.104	-1.22	0.225
γ_i	0.124	3.57	0.000
δ_i	0.058	1.80	0.074
α_{j0}	2.04720e-006	2.66	0.009
α_{j1}	0.226	1.64	0.102
β_{jt}	0.098	0.69	0.489
Student-t df	6.480	2.25	0.026

Both γ_j and γ_i are strongly significant as shown in table 3.11.1 which suggests strong mean spillover effects from the spot to the NDF market and from the NDF market to the spot market in the post-reform period. Neither δ_j nor δ_i is found significant to a level below 5% in table 3.11.2 which points to lack of obvious volatility spillover between the two markets in the post-reform period, though a positive δ_i is found significant to a level below 8%, suggesting some weak volatility spillovers from the NDF to the spot market. This finding of

two-way mean spillover effects is consistent with the Granger test results and can be justified by several observations covered in chapter 2.

First, the July 21 reform broke the super-stability of the onshore spot rate and allowed more freedom in rate movements, thus the onshore spot rate changes have shown a stronger correlation with the offshore rate changes.

Second, after the effort to transform trading arrangements, market makers now have a larger role in the determination of the exchange rate. Central bank's intervention has become less frequent and its way of control in the foreign exchange market has also been changed. Supply and demand factors including offshore supply and demand will then exert more influence on the less manipulated or distorted spot rate onshore, which corroborates our empirical result of a mean spillover effect from the NDF to the spot rate.

Third, as discussed in chapter 2, the onshore spot rate enters the calculation of the NDF settlement rate and there's evidence that the RMB NDF market is highly speculative with its pricing primarily based on the expectation of future spot rate level in the onshore market rather than the interest rate parity. The NDF rate is in turn highly sensitive to the rate changes and policy moves in the onshore spot market and in this sense, the spot rate will lead the NDF rate.

Fourth, reform in the foreign exchange market has broadened market access in the onshore spot market. On the other hand, capital control is no longer biased towards capital outflow but supporting domestic enterprises, institutions and individuals' direct investment and financing or investing activities in offshore or overseas financial markets. These trends of greater access for local players to the offshore NDF markets and offshore players greater access to onshore markets have already resulted in a two-way mean spillover effects between the two markets in the post-reform period. The spillover effect will become stronger with these new reform measures coming into full effect, however, since the post-reform sample data used in this thesis only cover the market performance in a short period (8 months) immediately after the reform, this cross-border market access effect is rather limited, which is reason why the mean spillover from the spot market to the NDF market is much stronger (a coefficient of 0.928) than from the NDF market to the onshore spot market (a coefficient of 0.124). As discussed in chapter 2, the RMB NDF market is highly speculative in nature while the onshore spot market is highly regulated with a membership-based trading platform and strict entry

requirements. The two markets are still rather distinct in terms of market participants, trading purposes and market functions, thus volatility contagion effects are not detected in the post-reform period using our data sample.

4. Summary and Conclusion

The July 21 reform and the ensuing reforms in the foreign exchange market abandoned the *de facto* currency peg and introduced certain flexibility in the RMB exchange rate and opened up the domestic foreign exchange market in a way to allow an interaction between this market and other markets, especially the offshore NDF market.

Preliminary graphs and statistics indicate/show salient differences in the two markets dynamics before and after July 21, 2005. Both the mean and volatility of the onshore spot rate changes jumped in the post-reform period, so did the volatility of the NDF rate change, though to a lesser degree. Furthermore, the stationarity of the onshore spot rate series found in the pre-reform period no longer holds after the reform. Deeper analyses of the market dynamics in the post-reform period were carried out with a co-integrating relationship or long-run equilibrium relationship between the onshore spot rate change and the NDF rate change identified by the Johansen co-integration test, reflecting the impact that the reform had on the inter-market relations. Two-way Granger causality proved the presence of feedback effects in both directions between the offshore NDF market and the onshore spot market. An AR-ARCH (1) model for the NDF rate change and a GARCH_t (1, 1) model for the spot rate change were constructed and attested to the strong mean spillover effects from the NDF market to the onshore spot market as well as from the onshore spot market to the NDF market with volatility spillover effects between the two markets still absent.

From these results, we can conclude that the insulation of the onshore spot market is clearly broken after the introduction of a series of reforms measures around July 21, 2005 when the market access is broadened, the trading arrangement is supplemented with a market-making and quote-driven system, the ban on outward capital flows is gradually lifted, the central bank relegates part of the control to market forces and the exchange rate increasingly reflects market supply and demand. Taken together, these reforms have enhanced and will further strengthen the inter-relation and mutual influences between the onshore spot market and the offshore market. Even though the volatility contagion effects remain obscure, the possibility can not be ruled out that this effect will emerge in the future with further deregulation and liberalization, so the regulators should be on guard. At the current stage, the onshore spot

market is found to have a larger influence on the offshore market than the other way around, but which market will dominate in the future remains to be seen.

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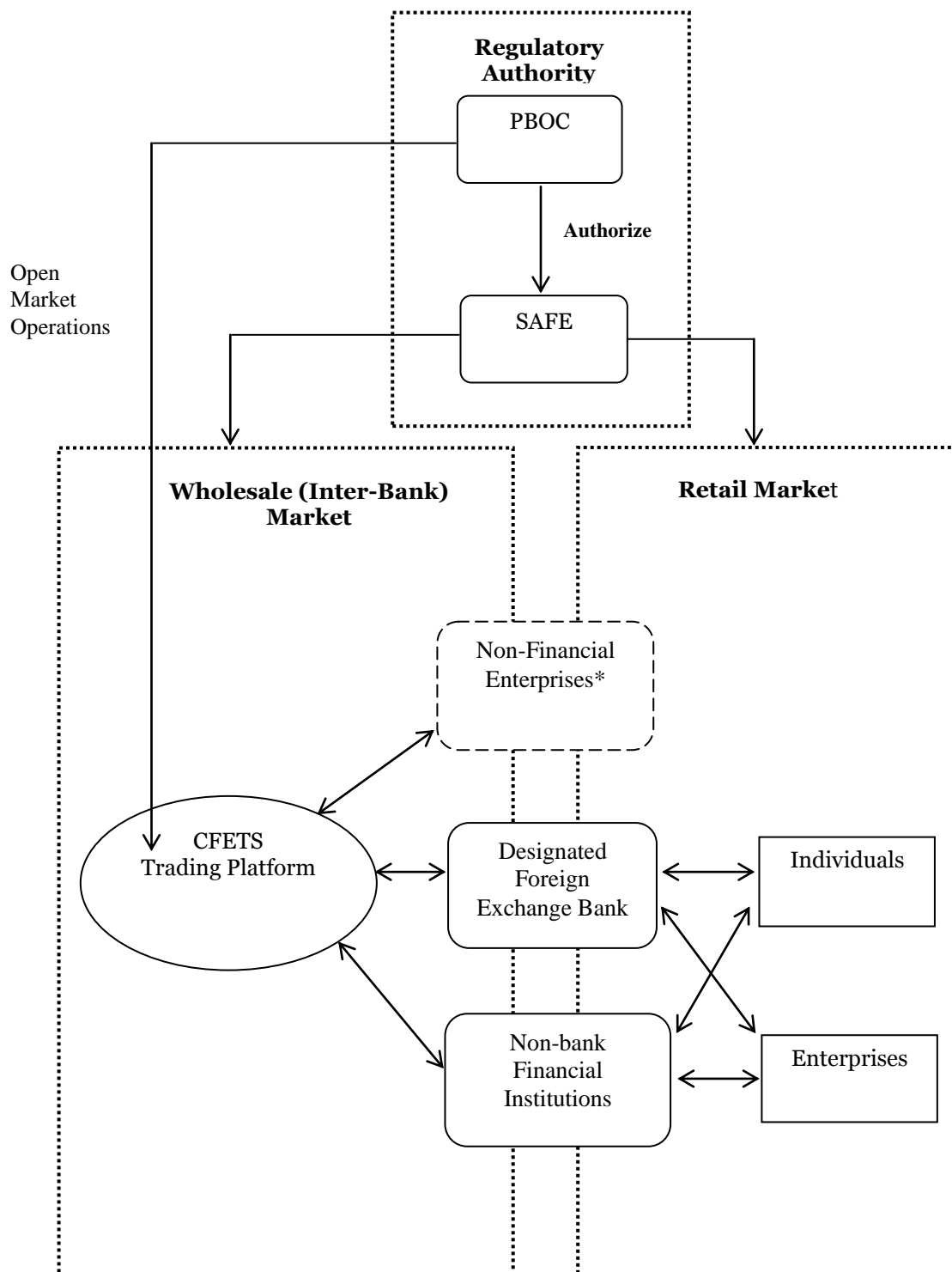
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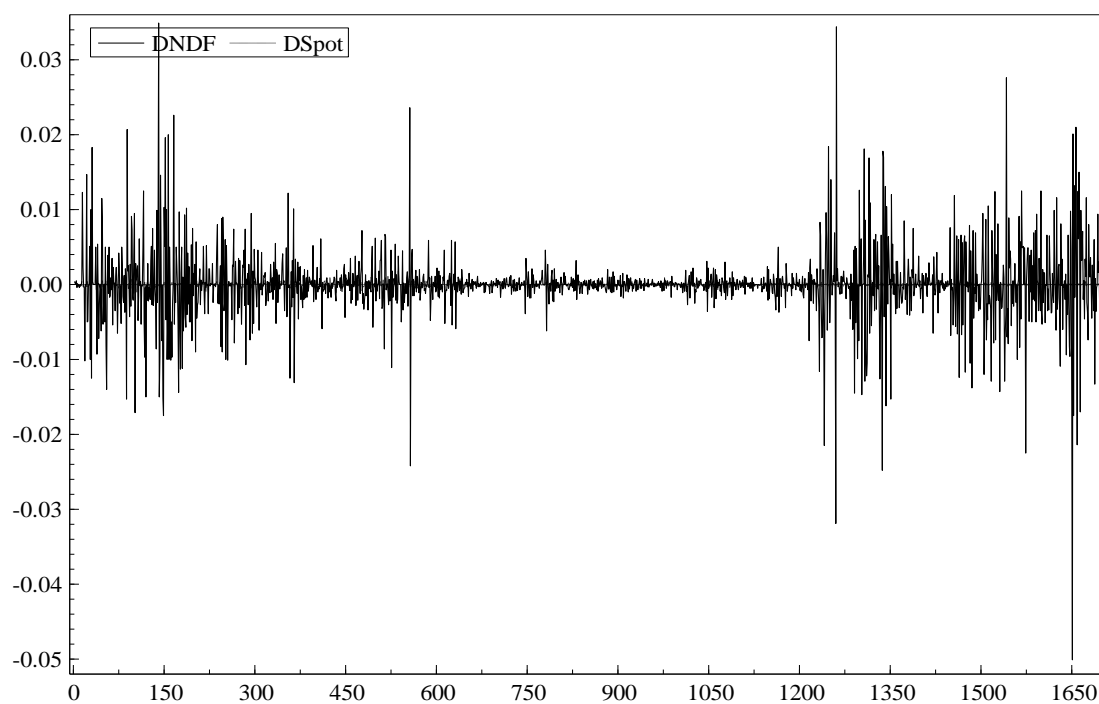
Appendix 1: Figures and Tables

Figure A.1.1 Organization of China's Foreign Exchange Market



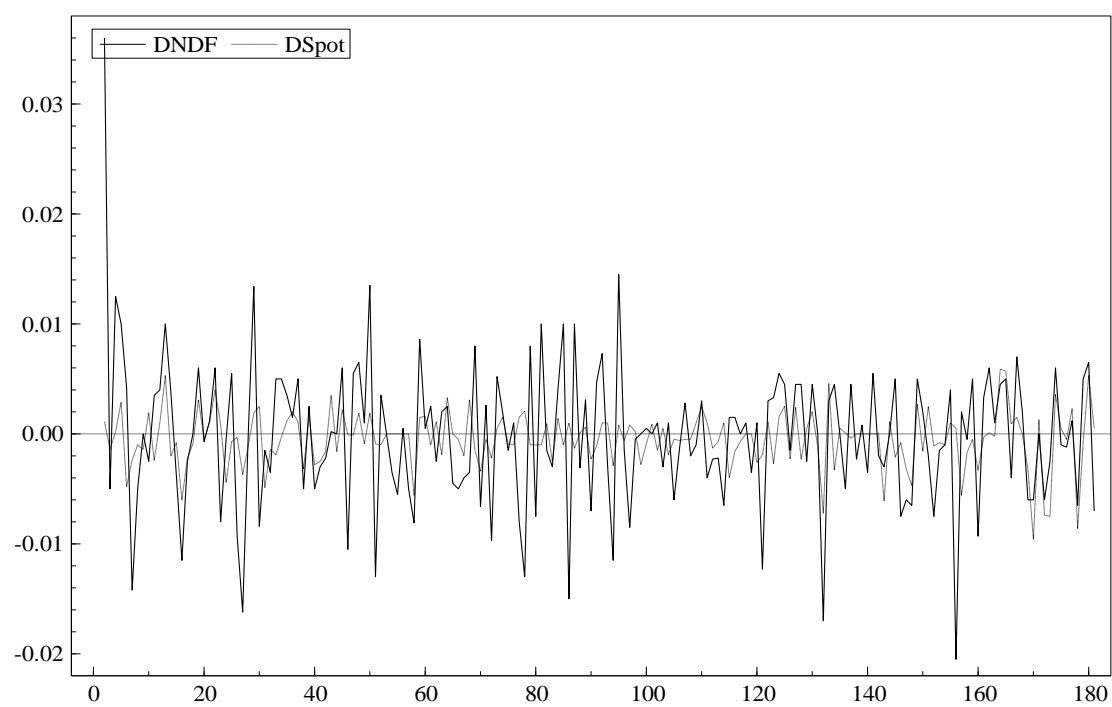
* There were no non-financial enterprises trading in the inter-bank foreign exchange market until March 2006.

Figure A.1.2: First difference of NDF and Spot closing rates, pre-reform period



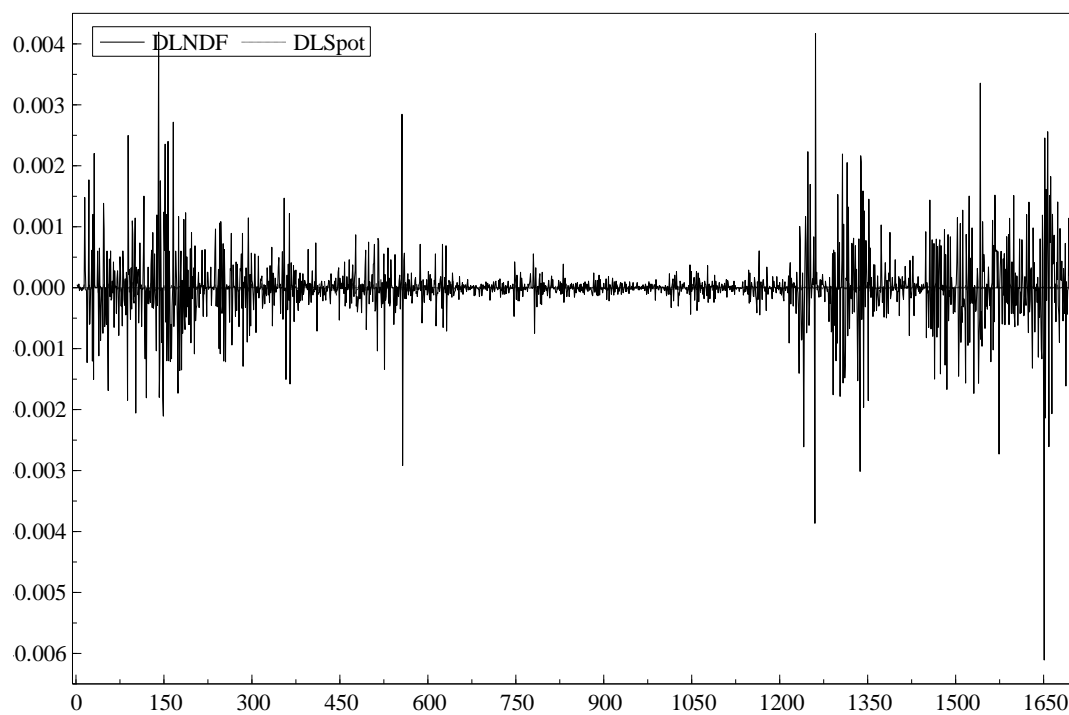
Source: Reuters.

Figure A.1.3: First difference of NDF and Spot closing rates, post-reform period



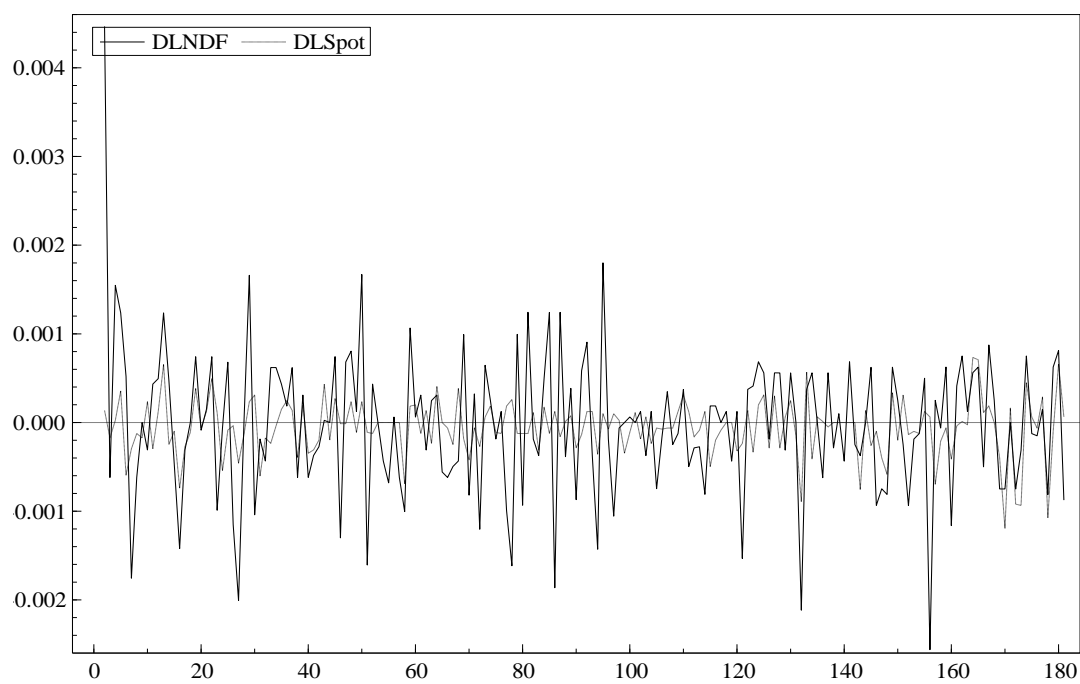
Source: Reuters.

Figure A.1.4: Percentage change of NDF and Spot closing rates, pre-reform period



Source: Reuters.

Figure A.1.5: Percentage change of NDF and Spot closing rates, post-reform period



Source: Reuters.

Table A.1.1 : F and Related Statistics for the Sequential Reduction from VAR (5) to VAR (2)

Null Hypothesis				Maintained Hypothesis			
System	SC	AIC	L	VAR (5)	VAR (4)	VAR (3)	VAR (2)
VAR (5)	-16.34	-16.73	1494.57				
↓				2.223			
VAR (4)	-16.40	-16.73	1489.87	[0.07]			
↓				(4,328)			
VAR (3)	-16.50	-16.75	1488.21	1.509	0.783		
↓				[0.15]	[0.54]		
VAR (2)	-16.60	-16.78	1486.49	(8,328)	(4,332)		
↓				1.285	0.80361	0.827	
VAR (1)	-16.65	-16.76	1480.42	[0.23]	[0.60]	[0.51]	
↓				(12,328)	(8,332)	(4,336)	
VAR (1)	-16.65	-16.76	1480.42	1.717	1.526	1.903	2.985
				[0.04]*	[0.11]	[0.06]	[0.02]*
				(16,328)	(12,332)	(8,336)	(4,340)

Notes:

1. L denotes log-likelihood while SC and AIC are Schwarz and Akaike information criteria respectively.
2. F statistic tests the null hypothesis in the first column against the maintained hypothesis indicated in the second row. The tail probability is reported in square brackets and the degrees of freedom for the F statistic in parentheses.

Appendix 2: Descriptive statistics

Skewness ($\sqrt{b_1}$) and Excess kurtosis (b_2) are defined in (A.2.1) and (A.2.2) respectively:

$$(A.2.1) \quad \sqrt{b_1} = \frac{m_3}{m_2^{3/2}}, \text{ in which } m_i = 1/T \sum_{t=1}^T (X_t - \bar{X})^i, \bar{X} = 1/T \sum_{t=1}^T X_t$$

$$(A.2.2) \quad b_2 - 3 = \frac{m_4}{m_2^2} - 3$$

The AR 1-j test is the Lagrange-multiplier test for j^{th} order residual autocorrelation under the null hypothesis that there is no residual autocorrelation (i.e. that the errors are white noise).

The ARCH 1-j test tests for j^{th} order autoregressive conditional heteroscedasticity in the error term (Engle, 1982). The null hypothesis is that $\gamma = (\gamma_1, \dots, \gamma_j)' = \mathbf{0}$ in (A.2.3).

$$(A.2.3) \quad E(u_t^2 | u_{t-1}, \dots, u_{t-j}) = c + \sum_{i=1}^j \gamma_i u_{t-i}^2$$

The Hetero test is based on White (1980) and involves an auxiliary regression of the estimated residual on the original regressors and all their squares with a null hypothesis of unconditional homoscedasticity and the alternative that the variance of the error term depends on regressors and all their squares. Hetero-X test is a general test for heteroscedastic errors with a null that the errors are homoscedastic or if heteroscedasticity is present, it is unrelated to the regressors. Normality test assumes a null of normality, using χ^2 critical values. A more detailed explanation of different diagnostic tests can be found in Doornik and Hendry (2001).